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SMALL AUXILIARY POWER SYSTEMS

FOR SHELTERS

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SUMMARY

OF

RESEARCH REPORT

SMALL AUXILIARY POWER SYSTEMS
FOR SHELTERS

OCD-OS-62-282

SCOPE OF WORK OF CONTRACT

The investigation of small auxiliary power systems for shelters was divided into two seperate categories;

1. The Contractor in consultation and cooperation with the Government devised several more or less conventional power systems which are designed to overcome environmental difficulties of employing commercially available engine-generator sets to the fullest advantage in shelters. More specifically this work included:

   a. A comparative evaluation of engine-generator systems in sizes below 5 kva for use in shelters.

   b. Development of direct means for removing objectionable heat from the shelter.

   c. Determination of parameters and selection of practicable apparatus for benefically utilizing waste heat.

   d. Preparation of criteria for the selection, installation, operation and maintenance of small electric power systems and appurtenances.

   Experimental methods were not used. Consideration was given to small Diesel engines, gas turbines, spark-ignition engines using LPG or gasoline fuels, and fuel storage. Various types of generators and methods of excitation were compared and evaluated.

2. For purposes of evaluation, two preliminary designs were prepared for an electric power system package having an output of 5 kva using a condensing (or possibly noncondensing) thermodynamic cycle with a vapor engine and low-pressure, relatively safe, flash boiler for use of gas or oil as a primary fuel, but capable of also using hand-fired coal, wood or combustible waste materials as alternate fuels.

   The design stresses simplicity and economy, but attempts to incorporate the necessary safety interlocks and functional devices.

APPROACH

The following system requirements of a satisfactory small auxiliary power system for shelters were established:

1. Power requirements - Output between 0.5 and 5.0 kva of 110 volt, 60 cps, AC power working into a resistive or 0.8 lagging power factor load (motors).

2. Storage requirements - The engine-generator set and fuel must be "stored" for a period of 10 years and be quickly put into continuous operation for a 3-week period.

3. Operational requirements - The power system is assumed to be operated by inexperienced personnel; air

for combustion is obtained from exhausted
shelter air; installation is such that ob-
jectionable waste heat, noxious fumes, and
noise level of operation are controlled.

A form letter was sent to 75 manufacturers of engine-generator
sets listed in the Thomas Register asking for electrical specifications,
availability, price, and servicing procedures for their small power
units. Thirty-five replies were received and a personal interview
trip was arranged with the chief engineers of several firms in the
upper Midwest. The data obtained were used in a comparative
evaluation of available equipment.

Storage characteristics of various fuels was discussed with en-
gine manufacturers and representatives of two major oil companies
Storage of LP Gas was discussed with a representative of the LPG
Association.

The response to a letter concerning available low-capacity waste
heat recovery equipment was generally of little value. Thus the
major systems presented are based on engineering experience of
the contractor.

A literature search conducted during an earlier investigation was
the basis for selection of working fluid, boiler and furnace construc-
tion, and general design of a hermetically-sealed, turbine-driven
generator. The results of recent investigations of small solid-fuel
furnaces suggest that the design is based on conservative combustion
volume requirements. The design of a condensing or non-condensing
steam driven generator was greatly aided by a consultant with over
20 years experience with steam automobiles.

LIMITATIONS

This report, in general, does not clearly distinguish between
the divergent requirements for engine-generator sets in fallout
shelters, blast shelters, BW/CW shelters, and closed shelters.
Many of the heat and noxious gas control schemes would not function
with a nearby fire storm; also the limited back pressure allowed for
engines (and supercharging effects) would hamper operation in times
of severe ambient overpressures after a blast. In the absence of a
fire storm, liquid cooling with an external radiator is advantageous
since the rate of shelter ventilation would not necessarily have to be
increased to operate the electric unit. In a closed shelter well
water is almost a necessity for continued power generation. How-
ever, in view of the high cost of oxygen storage, it may be neces-
sary to discontinue power generation in a closed shelter. If the
shelter is primarily for fallout protection, the popular air-cooled
engine-generator set would generally be satisfactory. Hence, it is

assumed that the shelter designer will use the suggested methods with due regard to the may other factors necessary in shelter design.

CONCLUSIONS

The standard engine-generator set with a heavy-duty, four-stroke-cycle, internal-combustion engine and a wound-rotor, rotating-armature, air-cooled generator is satisfactory for many shelter applications (10-year "storage" followed by operation). Of course a completely closed shelter would present very complex problems (air supply, noxious gas control, cooling, etc.). The proper method of "storage" consists of weekly operation for one half hour at part load (exercising).

The storage life expectancy of internal-combustion engine fuels may be rated as LP gas (best), Diesel fuels (good), and gasoline (poor). The most satisfactory method of ensuring a useable fuel supply is periodic replacement of the fuel. There is some evidence that low-temperature storage would increase the period between necessary replacements.

Satisfactory operation of engine-generator sets in below-ground structures appears to be possible by proper use of conventional equipment. Untrained personnel should be able to cope with most problems in starting and continued operation of the equipment when the exercising storage method is used.

The Rankine-cycle devices investigated (turbines or reciprocating engine prime movers) could be readily developed for shelter application but the over-all system would cost five times as much as an equivalent size (5kva) engine-generator set. In addition, the thermal efficiency of the Carnot-cycle-limited device is less than one-third that of the engine-generator set, the equipment required is much more bulky, and the cooling requirements are much more severe. An integrated utility package in quantity procurement could reduce cost but low efficiency and heat rejection problems remain.

RECOMMENDATIONS

It is recommended that a development program be initiated to investigate the following three subjects:

1. There is a need for development of an accelerated life test to be used for evaluation of performance of various makes of engines when subjected to shelter application requirements ("storage" followed by a period of nearly constant duty).

2. Experimental data should be obtained to confirm whether or not cold storage will improve the lifetime of internal-combustion engine fuels and offer an economic advantage over periodic replacement of the fuel supply.

3. All of the novel concepts of engine-generator set cooling de-
    veloped during this study involve circulation of at least a limited
    amount of air past the engine-generator set. The heat flow
    patterns involved in these methods should be determined by actual
    tests. Also the worth of a "wind tunnel" construction should be
    determined.

The inefficient Rankine-cycle devices would not warrant further
consideration as small power sources for shelters unless solid
fuels are the n ost readily available fuel supply and means are
ueveioped for utilizing the large quantities of waste heat, such as
absorption air conditioning, air tempering, food warming, etc.

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CONTENTS (Cont)

FIGURES

FIGURES (Cont)

TABLES

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I.   ABSTRACT

An adequate supply of electrical power is a service having great potential utility in a shelter and in some cases might be essential for full occupancy or survival. If there is a good probability that commercial power sources would be disrupted, an auxiliary power system would be necessary to secure continuity of this service and the tangible benefits to be derived therefrom.

Conventional and unconventional methods of storage of engine-generator sets and a fuel supply are discussed; recommendations are made based on the present state of the art.

Methods for removal of waste heat and noxious fumes and control of noise and vibration are discussed to facilitate installation of engine-generator sets in shelters.

Several means of utilizing engine waste heat for other shelter activities are presented and discussed; also means of utilizing more conventional heating devices are considered.

Installation, maintenance, and repair procedures as well as operating instructions are discussed in detail.

Finally, a thermodynamic analysis and preliminary design of two Rankine-cycle power generators utilizing a turbine and reciprocating engine respectively are included. Preliminary designs of the required auxiliary equipment are presented and discussed in some detail.

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II. SUMMARY

The conclusion that a heavy-duty engine-generator set
operated at part load weekly using LP gas fuel is a
promising auxiliary power system was based on inter-
views with engine-generator-set manufacturers, oil company
representatives, and LPG Association personnel. Cheaper
air-cooled engines have very limited life for this application.
However, presently there is no acceptable test to guarantee
satisfactory performance for any engine. None of the engine
fuels can be stored successfully for 10 years; however, cold
storage probably would increase storage life.

Heat-removal and noxious-gas-control methods presented
are well suited to fallout shelters. A closed shelter would
probably require stopping the auxiliary power equipment
(and use batteries) in order to use expensively generated
oxygen only for sustaining life. A blast shelter must provide
protection from excessive back pressure on the engine
exhaust and prevent supercharging in case of severe ambient
overpressures. The effect of chemical and biological war-
fare gases on engine operation is unknown. The use of
large amounts of filtered cooling air for air-cooled engines
is unattractive because of large pressure drops through
blast valves, CW/BW filters, and particulate filters.

Generally, the manufacturers of engine-generator sets have
had limited experience with the many possible difficulties
that auxiliary power systems will experience in shelter
applications. The petroleum refiners have had little need
for long term storage techniques for fuels.

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III. CONCLUSIONS

The standard engine-generator set with a heavy-duty, four-stroke-cycle, internal-combustion engine and a wound-rotor, rotating-armature, air-cooled generator is satisfactory for many shelter applications (10-year "storage" followed by operation). Of course a completely closed shelter would present very complex problems (air supply, noxious gas control, and possibly heat rejection). The proper method of "storage" consists of weekly operation for one half hour at part load (exercising).

The storage life expectancy of internal-combustion engine fuels may be rated as LP gas (best), Diesel fuels (good), and gasoline (poor). The most satisfactory method of ensuring a usable fuel supply is periodic replacement of the fuel. There is some evidence that low-temperature storage would increase the period between necessary replacements.

Satisfactory operation of engine-generator sets in below-ground structures appears to be possible by proper use of conventional equipment. Untrained personnel should be able to cope with most problems in starting and continued operation of the equipment when the exercising storage method is used.

The Rankine-cycle devices investigated (turbines or reciprocating engine prime movers) could be readily developed for shelter application but the over-all system would cost at least five times that of an equivalent size (5 KW) engine-generator set. In addition, the thermal efficiency of the Carnot-cycle-limited device is less than one-third that of the engine-generator set, the equipment required is much more bulky, and the cooling requirements are much more severe. An integrated utility package in quantity procurement could reduce cost but low efficiency and heat rejection problems remain.

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IV. RECOMMENDATIONS

It is recommended that a development program be initiated to investigate the following three subjects:

1. There is a need for development of an accelerated life test to be used for evaluation of performance of various makes of engines when subjected to shelter application requirements ("storage" followed by a period of nearly constant duty).

2. Experimental data should be obtained to confirm whether or not cold storage will improve the lifetime of internal-combustion-engine fuels and offer an economic advantage over periodic replacement of the fuel supply.

3. All of the novel concepts of engine-generator set cooling developed during this study involve circulation of at least a limited amount of air past the engine-generator set. The heat flow patterns involved in these methods should be determined by actual tests. Also the worth of a "wind tunnel" construction should be determined.

The inefficient Rankine-cycle devices would not warrant further consideration as small power sources for shelters unless solid fuels are the most readily available fuel supply and means are developed for utilizing the large quantities of waste heat (absorption air conditioning, air tempering, food warming, etc.).

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V. SYSTEM REQUIREMENTS

A certain number of requirements for a Small Auxiliary Power System for Shelters are fixed by the contract (OCD-OS-62-282) and certain requirements are indirectly determined by the nature of the power load and the nature of the equipment. These system requirements are discussed below:

A. Power Output and Utilization

1. The size of the units considered is 5 KVA output maximum as this is fixed by the contract. The minimum power output is 0.5 KVA. This minimum limitation was imposed to eliminate spending time and effort on devices such as springs, thermocouples, etc. that would be impractical in the 0.5 to 5 KVA range.

2. The nature of the power output is assumed for discussion purposes to be 110 volt, 60 cycle, AC current except where specific conditions result in other requirements. This assumption is not really a requirement in that if a different generator has been assumed, the voltage and the frequency would have been different. The effects of voltage, amperage, and frequency are discussed; hence fixing the voltage and frequency are merely conveniences and any different voltage and frequency can be evaluated.

3. The load is assumed to be essentially lighting, heating, communications, air conditioning and ventilation; these only affect the power factor for the generator load and the starting requirements. The nature of these loads is such that the power factor is 0.8 to 1.0 lagging (inductive load). Thus the power factor is considered a parameter that varies from 0.8 to 1.0 with an inductive load. If some capacitive load were included in the shelter, it is extremely improbable that it would exceed the inductive (motor) load; therefore, capacitive load is considered to improve the power factor.

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B.   "Storage" Characteristics

1.   It is required that the unit be capable of operation
after being on stand-by duty for ten years.   The
period of operation is considered to be three weeks
continuous operation.   If the expected equipment life
is shorter than three weeks continuous operation, the
shorter time is specified.   In most cases a scale
factor can be applied to change the three weeks to
two weeks or any other shorter time period.   The
scaling could also be extended to longer times for
cost analysis and other purposes, providing that the
life expectancy of the equipment is not exceeded.

C.   Operation

1.   In general the equipment is assumed to be operated
by inexperienced personnel.   However, when experi-
ence is particularly valuable, this factor is also
considered.

2.   There must be sufficient air for a combustion process
to be supported or the combustion will not occur.
Therefore, it is assumed that this air is available.
However, it is also assumed that there will not be
sufficient air available to rely on cooling the power
producer by use of filtered shelter air.   When such
cooling occurs, it is considered an "unexpected"
benefit from the over-all shelter operation.   The
utilization of this "unexpected" benefit for cooling is
considered, when advisable, but it is not relied upon
as a cooling means.

3.   The functional characteristics of the power source are
inspected in regard to (a) objectionable heat liberation,
(b) noxious fumes, (c) safety and (d) noise level.

4.   The functional characteristics must be consistent
with the shelter application in that selected power-
generating equipment and recommended utilization
will not result in excessive starting loads or over-
loading of the power generator.

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VI. INTERNAL-COMBUSTION ENGINES AS PRIME MOVERS

A. Types

1. Diesels

a. Availability

Engine-generator sets that use Diesel engines are commercially available. A partial list of manufacturers of these units are Onan, Witte, Winpower, Kohler, American Marc, and Nordberg. This list shows that availability would not be a problem for the wide-spread usage of these units in shelters, providing sufficient time was allowed for their manufacture.

Although several foreign Diesel-engine manufacturers have domestic distribution (Petter, Lister, Dietz, and Yanmar) and the engines are used by some domestic engine-generator-set manufacturers (Winpower), the costs and operating characteristics of the American engines presented in this section are typical of all engines.

b. Initial cost

Figure A1 is a graph of the initial cost per kilowatt of units produced by various manufacturers. The cost data were obtained recently and reflects current prices. The graph shows that it would be advantageous to favor the use of larger (5 KW) units instead of the smaller units unless reliability may require use of two smaller units.

c. Operating characteristics

The Diesel engine operates on the Diesel thermodynamic cycle as constructed in Fig. A2. The Otto cycle is also shown in the figure. The principle difference between the cycles is that the combustion process for the Diesel cycle is constant pressure, while combustion occurs at constant volume for the Otto cycle.

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FIG. A1   INITIAL COST OF DIESEL UNITS

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IDEAL DIESEL CYCLE

COMBUSTION →

PRESSURE

VOLUME

IDEAL OTTO CYCLE

COMBUSTION

PRESSURE

VOLUME
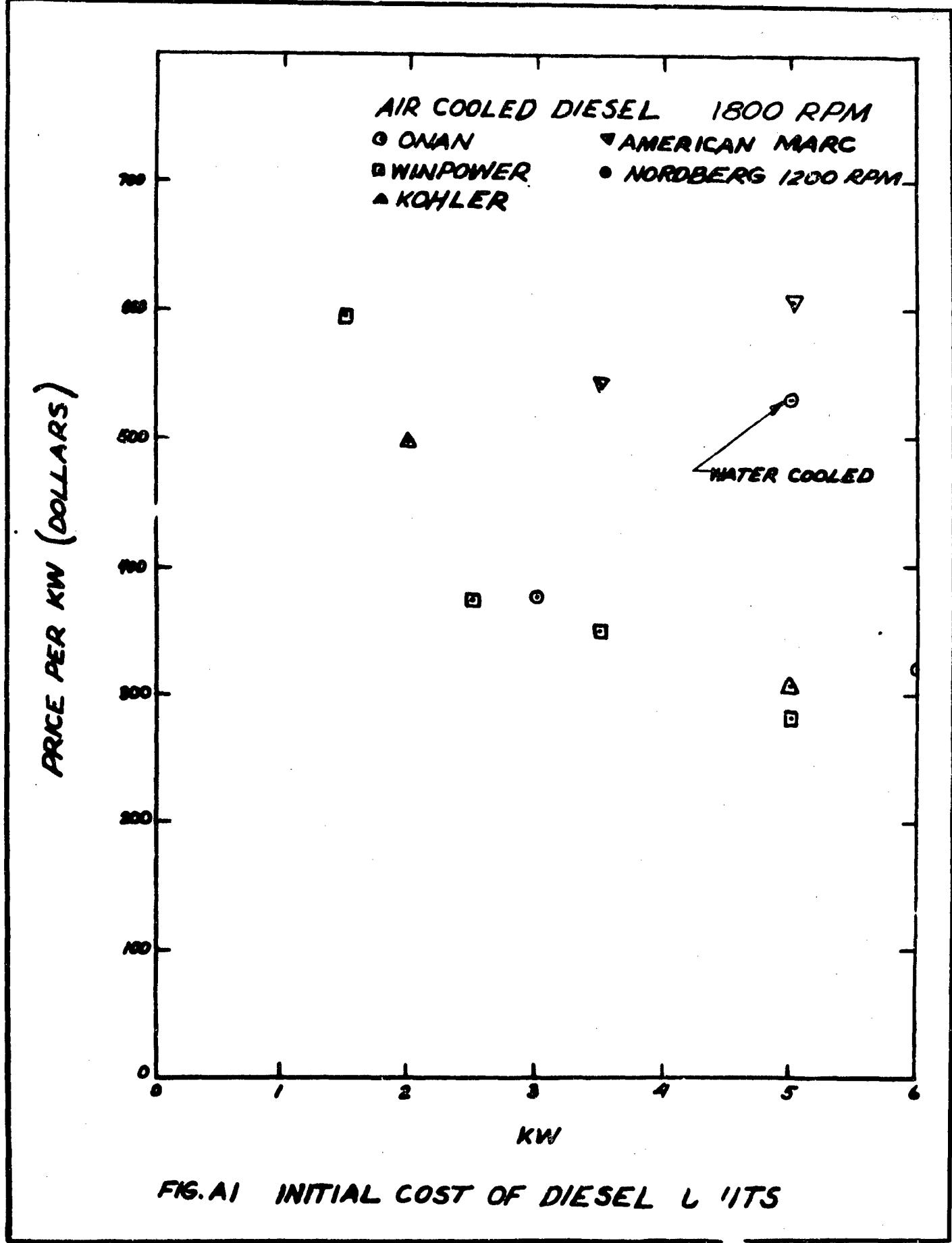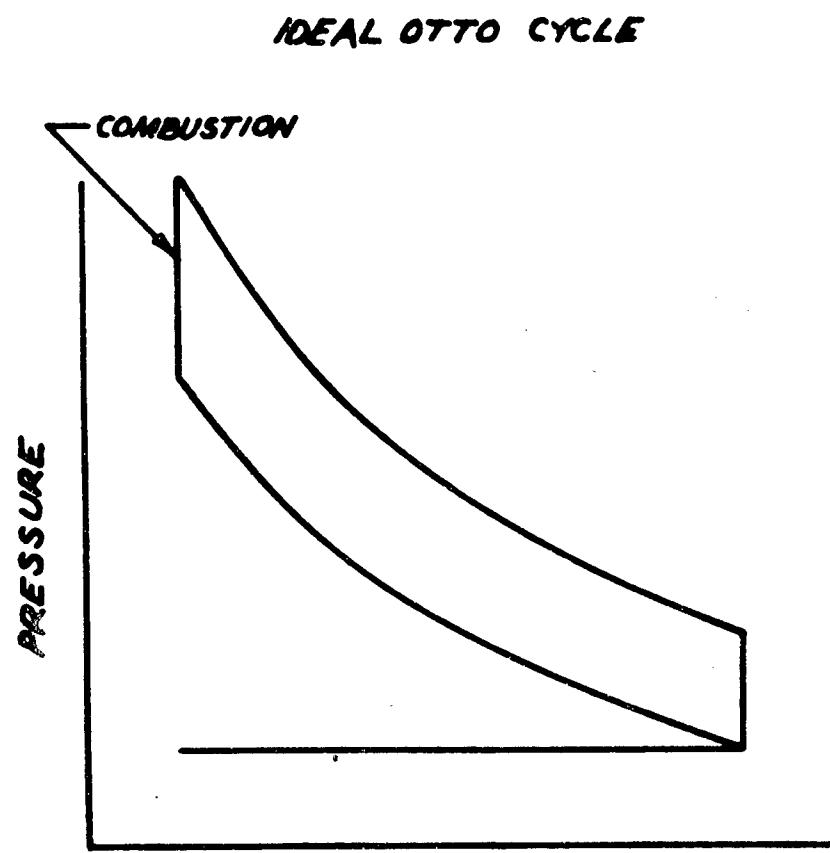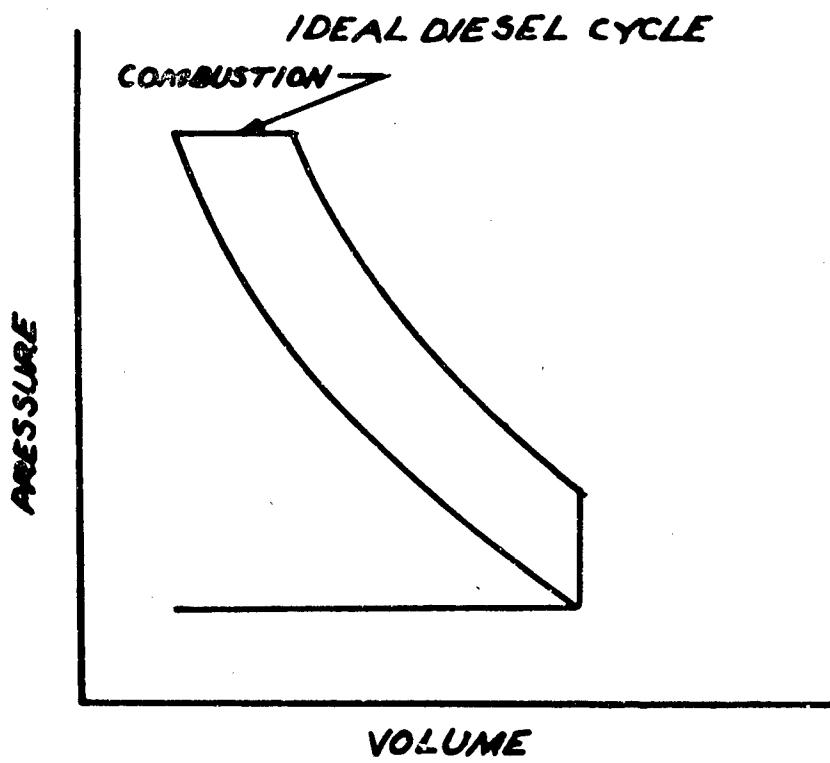
FIG. A2   IDEAL DIESEL AND OTTO CYCLES

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Functionally, the main difference is that the
Diesel engine uses a high pressure fuel-injection
system and does not use a spark-ignition system.
The gasoline engine (Otto cycle) has a low-pressure
fuel feed system (carburetion system) and a spark-
ignition system. The Diesel engine requires higher
pressure ratios, and a better fuel economy is
obtained as shown in Fig. A3. The specific fuel
rate is 25 to 50 per cent better for a Diesel engine
as compared to a spark-ignition engine (in smaller
sizes). However, such factors as initial cost must
be considered when evaluating the economics of
the units.

Both Diesel and spark-ignition engines will have
to be exercised during the ten year stand-by
period unless future research and testing result
in satisfactory static-storage methods. The
Diesel has the greatest tendency to form carbon
deposits in the engine at lighter loads used during
exercising than do gasoline engines. These
carbon deposits can and do cause malfunctioning
of the engine. Therefore, it will be necessary to
exercise the Diesel engines at greater loads than
the gasoline engines. This adversely affects the
total fuel consumption; thus the total fuel con-
sumption required for exercising and during the
emergency may not be less than that of the
gasoline engine.

The part most likely to fail on the Diesel engine
is the injector. It could be replaced by a trained
person; the general public is not familiar with
the procedure.

Diesel engines are available that will run in
excess of 1000 hours at full load. This is the
life expectancy standard that has been placed
on engine generators in this study due to the
absence of data on effects of excercising an
engine for 10 years and then running the unit for
three weeks. This operation is considered to be
more severe than that encountered during con-
tinuous operation.

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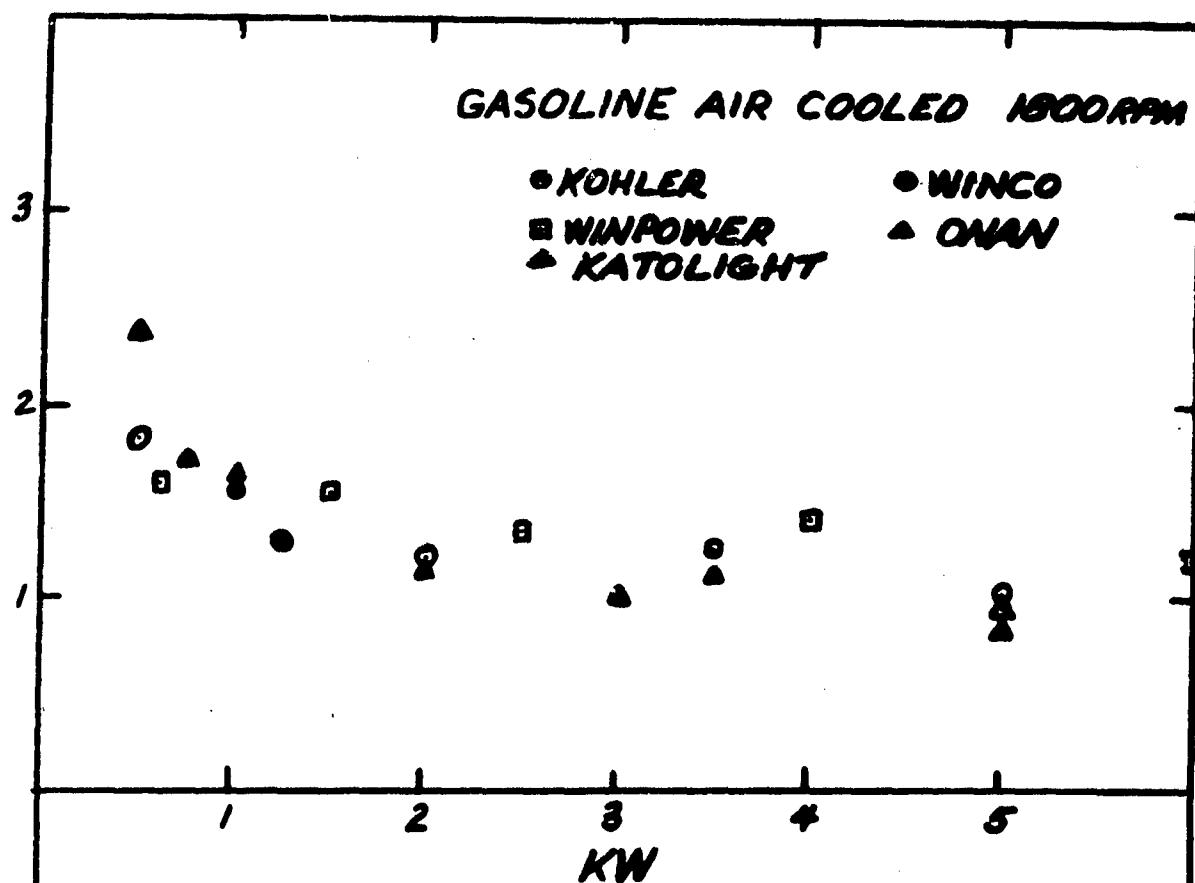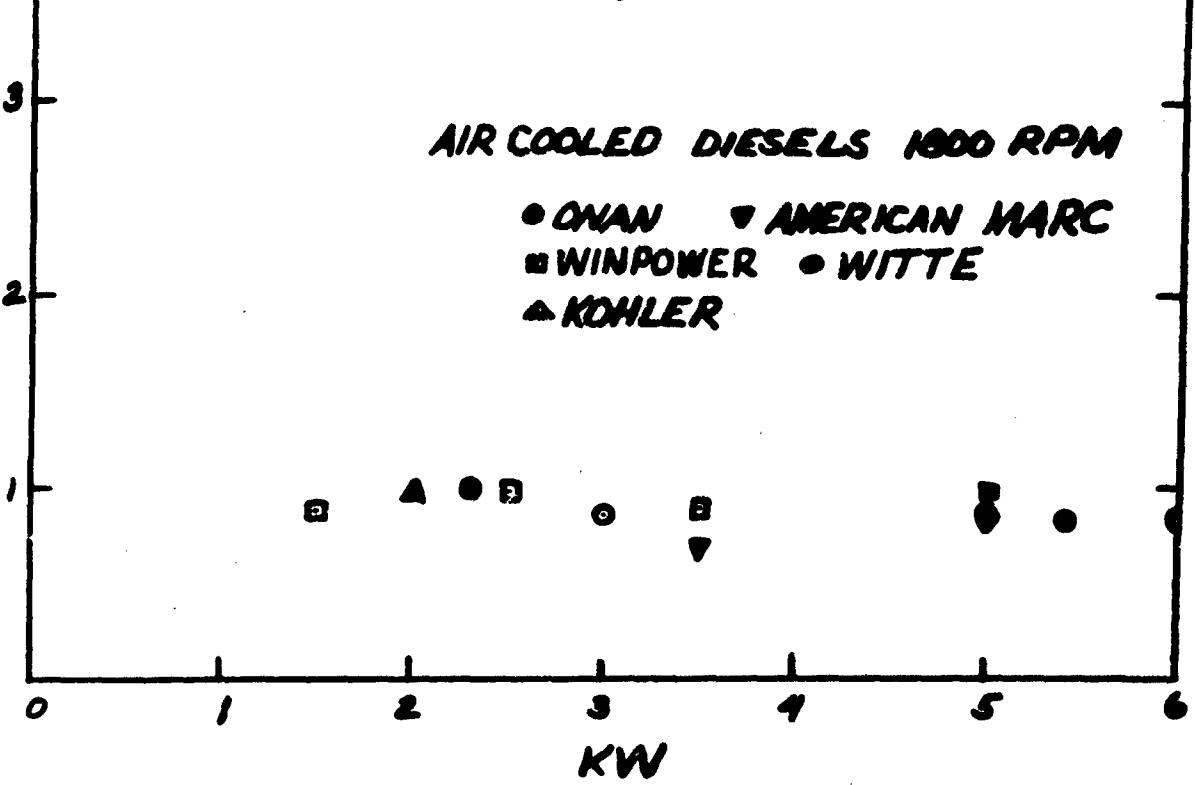
FIG.A3 FUEL RATE OF GASOLINE & DIESEL UNITS (1800 RPM)

d.   Fuel

The fuel for a Diesel engine would be either
No. 1 or No. 2 fuel oil.   Typical character-
istics are given in Table A1.

The No. 1 fuel oil would be recommended for
the shelter application because impurities
adversely affect the long storage requirements.
The aging characteristics of fuel oil are
formation of sludges and gums.   The gum will
clog small orifices in the injector and may
cause malfunctioning of the valves.   The
rating of storage characteristics of fuel is that
it is better than gasoline but not as good as LP
gas.   The estimated life of the No. 1 fuel oil is
2 years with a 5 year life probable with a
highly refined fuel stored with great care.   The
storage container should not contain copper or
zinc as these metals accelerate decomposition.
An inert gas such as nitrogen should be placed
over the fuel to prevent oxidation.   This
eliminates the possibility of venting the fuel
tank.

Examination of similar compounds indicate that
storage at $0^{\circ}F$ would be recommended to meet
the ten year life expectancy requirement.
This would have to be confirmed by experi-
mental investigation.

The ratio of cost of No. 1 fuel oil to gasoline
(excluding tax) is 0.8 and the ratio for No. 2
fuel oil is 0.7.

Fuel oil is less volatile than gasoline or LP
gas and is less hazardous for storage and
handling.

Table A1

Characteristics of Diesel Fuel

Property	No. 1	No. 2
1. Type	Distillate	Distillate
2. Color	Light	Amber
3. Weight (lb/gal)	6.7 - 6.9	6.9 - 7.3
4. Viscosity (centistokes)	1.6	2.6
5. Pour point	Below 0°F	Below 0°F
6. Impurities (%)		
Sulfur	0.1	0.4 - 0.7
Sediment, Water	Trace	Trace
Ash	Trace	Trace
7. Composition (%)		
Oxygen, Nitrogen	0.2	0.2
Hydrogen	13.2	12.7
Carbon	86.5	86.4
8. Heating Value (Btu/gal)	132,000 to 137,000	135,800 to 141,800

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2. Reciprocating Gasoline Engines

a. Cycle description

The reciprocating gasoline engine can be divided into two types (reference A1):* (1) two-stroke-cycle and (2) four-stroke-cycle. The two-stroke-cycle engine consists of one expansion stroke and one compression stroke (compressing an air-fuel mixture) during each revolution of the crankshaft. Fig. A4 is a diagram showing two-stroke-cycle engine operation. Ignition occurs approximately at the end of the compression stroke (shortly before the piston reaches the top of its stroke) and the power or expansion stroke follows. Toward the end of the expansion stroke, the exhaust ports are uncovered by the piston motion and the burned air-fuel mixture is exhausted from the system. Since the system exhausts to atmospheric pressure, there is a tendency for a residual amount of burned mixture to remain within the cylinder. Much of this residual gas is removed from the cylinder by allowing a fresh charge of unburned fuel-air mixture, which was originally compressed by the underside of the piston or some other external means, to enter the cylinder while the exhaust port is still open and scavenge the residual burned gases from the system. This naturally results in some waste of unburned air-fuel mixture. This entry of unburned air-fuel mixture charges the cylinder and the engine is then again ready for the compression stroke and the start of another cycle.

The purging operation requires that the unburned fuel-air mixture be compressed so that a pressure differential is available for forcing it into the cylinder. This is accomplished by using the crankcase side of the piston to act as the piston of a compressor. Air-fuel mixture is drawn into the crankcase through a one-way valve during the upward motion of the piston on the

*References are listed in the Bibliography and referred to by a letter and number in the text.

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EXPANSION
STROKE

EXHAUST &
SCAVENGING BDC

COMPRESSION
STROKE

TWO-STROKE CYCLE ENGINE
FIG. A 4

PRESSURE

COMBUSTION
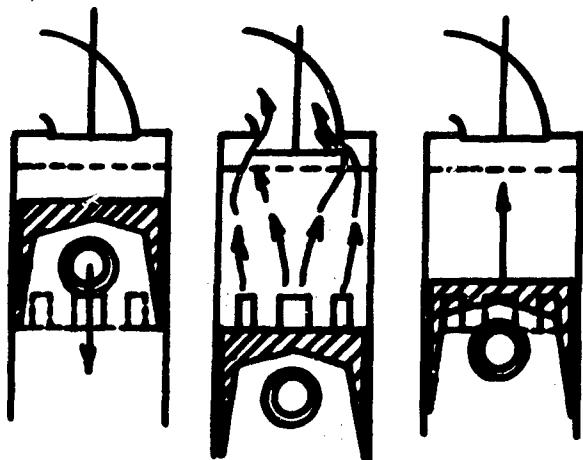
EXPANSION

EXHAUST (BLOW-DOWN)

COMPRESSION

VOLUME
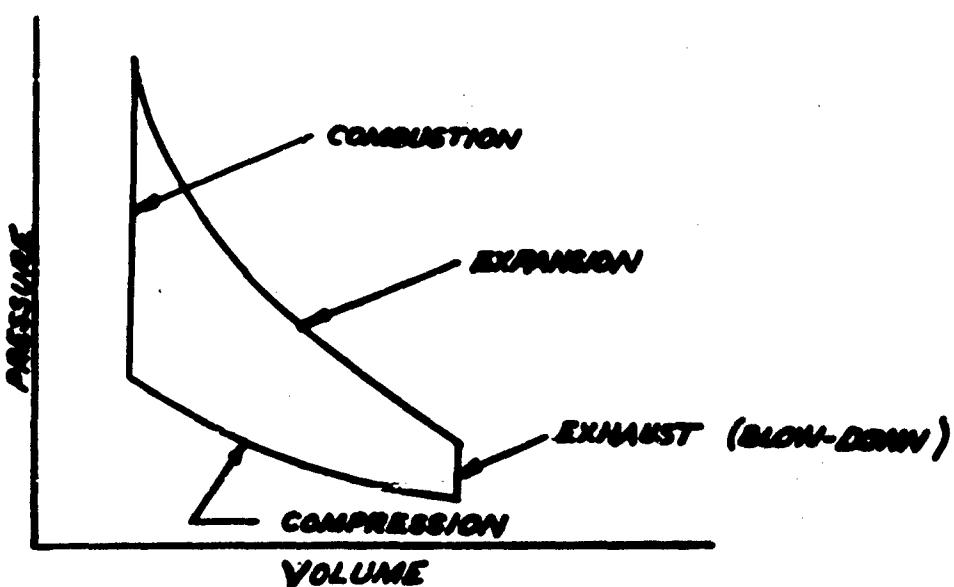
P-V DIAGRAM OF AIR-STANDARD OTTO CYCLE
FIG. A 5

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compression stroke due to the partial vacuum
created in the crankcase. This mixture is
compressed during the downward movement of
the piston and is available for charging the
cylinder at the proper time in the cycle. The
thermodynamic cycle is again shown in Fig. A5.

Ignition is normally accomplished by a spark
plug. Glow plug ignition may be used on
extremely small engines (model airplane
engines) but requires a special fuel to insure
proper timing of the combustion processes.
The use of the spark plug allows ignition to be
independent of the pressure in the cylinder and
permits conventional gasoline to be used as the
fuel. Spark plugs are generally used on the two-
stroke-cycle engines in the size range (1 to 10 hp.)
that is of interest in this study.

Two-stroke-cycle engines, due to lack of an oil
reservoir in the crankcase, typically require
that the lubricant be pre-mixed with the fuel
before it enters the engine. This need for the
mixing of the fuel and the lubricant results in
poorer fuel storage if pre-mixed prior to use,
or it involves mixing during use. Higher
operating speeds (greater tendency towards
wear) have caused these engines to be eliminated
for the shelter application. This is consistent
with the fact that four-stroke cycle engines are
most commonly used on the better grade
generator sets.

Four-stroke-cycle, reciprocating, gasoline
engines also operate on the Otto cycle shown
in Fig. A5. The unburned air-fuel mixture is
compressed on the compression stroke and
ignited at the end of this stroke (shortly before
the piston reaches the top of its stroke) by
means of a spark plug. The expansion or power
stroke follows the combustion process. The
next stroke (exhaust stroke) forces the burned
gases from the cylinder, and the following
stroke, (intake stroke) creates a partial vacuum

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in the cylinder and draws a fresh charge of
unburned air-fuel mixture into the cylinder.
The cylinder is then ready for another compres-
sion stroke and repetition of the cycle.

b. Availability

Engine-generator sets using four-stroke-cycle,
spark-ignition, gasoline engines are available
from many manufacturers. The engines on com-
mercial units can be roughly divided into two
categories: (1) the low cost or economy units and
(2) the heavy-duty units. Functionally these
categories are distinguished by the life expect-
ancy of the units. The economy units have a life
expectancy of 300 to 600 hours while the heavy
duty units have a life expectancy of 1000 to 2000
hours. The main constructional differences are
that the economy units have many die-cast
components, steel valves and valve seats,
while the heavy-duty units tend to rely more upon
steel castings and have stellite valves and valve
seats. The heavy-duty units are recommended
for the shelter application.

c. Costs

Figure A6 presents cost data on 1800 rpm units
and Fig. A7 presents cost data on 3600 rpm units.
The lower cost for 3600 rpm units is largely due
to the fact that many 1800 rpm units contain a
3600 rpm engine operated at less than rated speed
and load. However, the effects of wear due to
higher speed make an 1800 rpm engine more suit-
able for shelter application. The two figures
again indicate (as in the case of Diesel units)
that utilization of a 4 or 5 KW machine gives a
lower first cost than two units of one half the
power output.

The fuel rate of between one and two pounds
per KW-hour is shown in Figs. A7 and A8.
The fuel rate is improved considerably as the
rating of the unit is increased, but the trend
is much less pronounced in the three to five
KW range. Figure A8 also reconfirms the
previous statement that Diesel engines are
more efficient than spark-ignition engines in these
smaller sizes.

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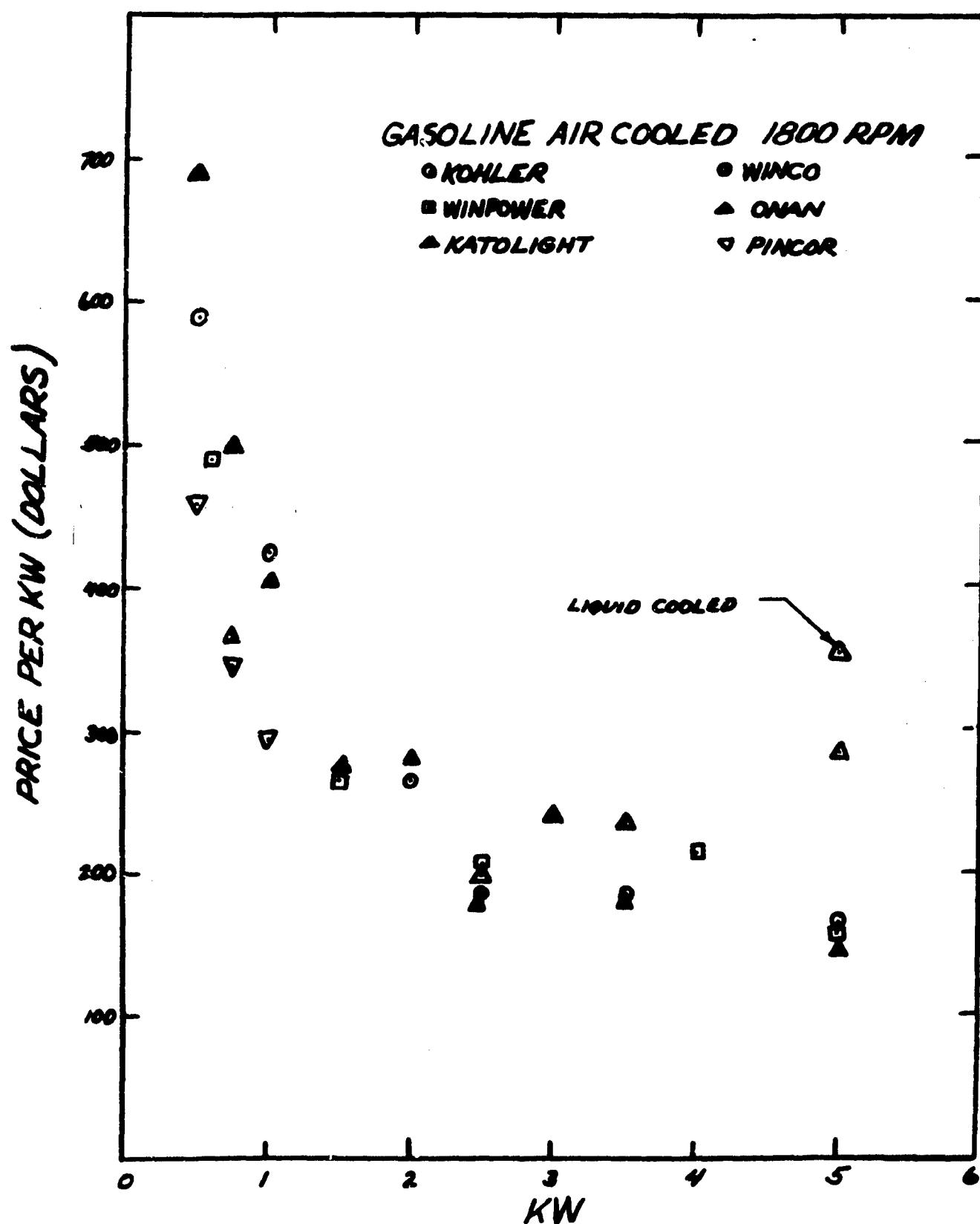
FIG. A6   INITIAL COST OF GASOLINE UNITS (1800 RPM)

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AIR COOLED 3600 RPM GASOLINE
- ● KOHLER   ● WINCO
- ▢ WINPOWER   ▲ ONAN
- ▲ KATOLIGHT   ▽ PINCOR
-          ✕ HOMELITE

POUNDS OF FUEL PER KWH

KW

AIR COOLED 3600 RPM
- ● KOHLER   ○ WINCO
- ▪ WINPOWER   ▲ ONAN
- ▲ KATOLIGHT   ▽ PINCOR
-          ✕ HOMELITE
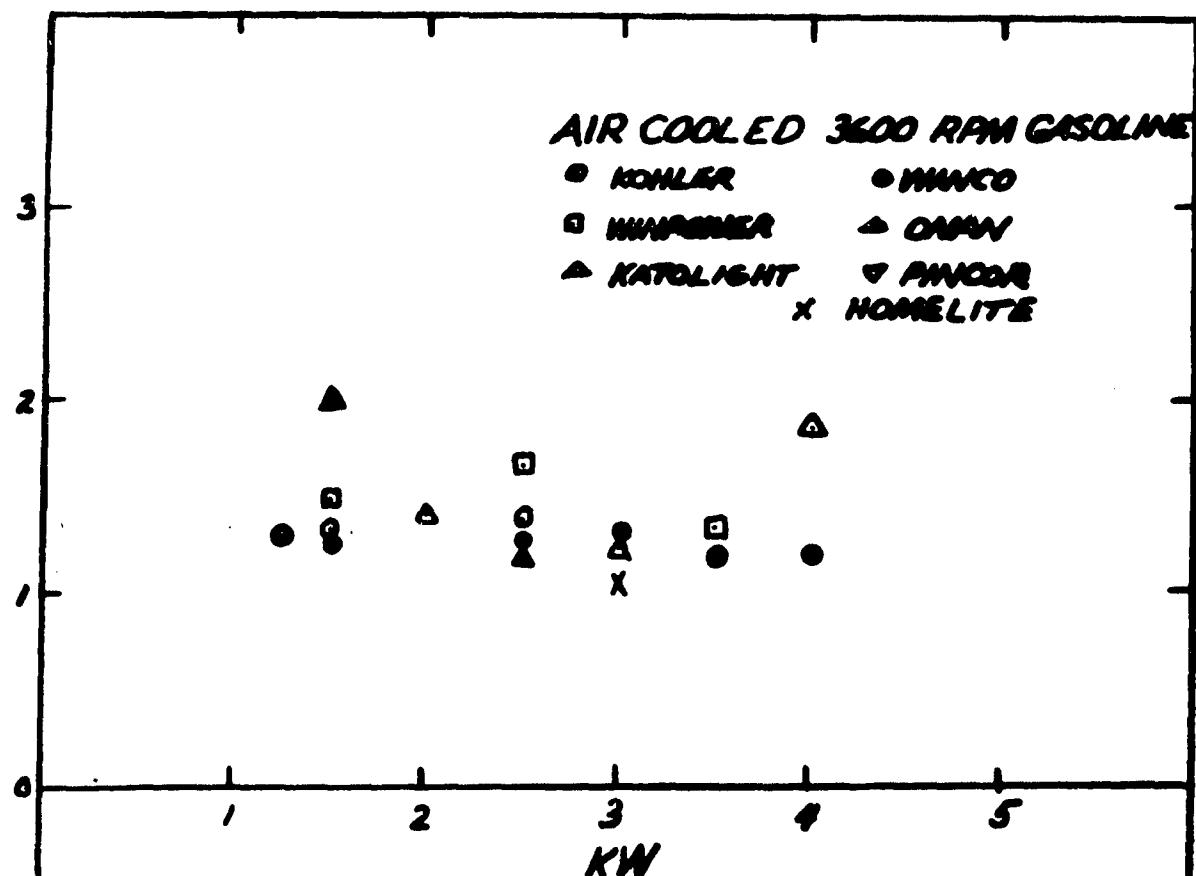
PRICE PER KW (DOLLARS)

KW
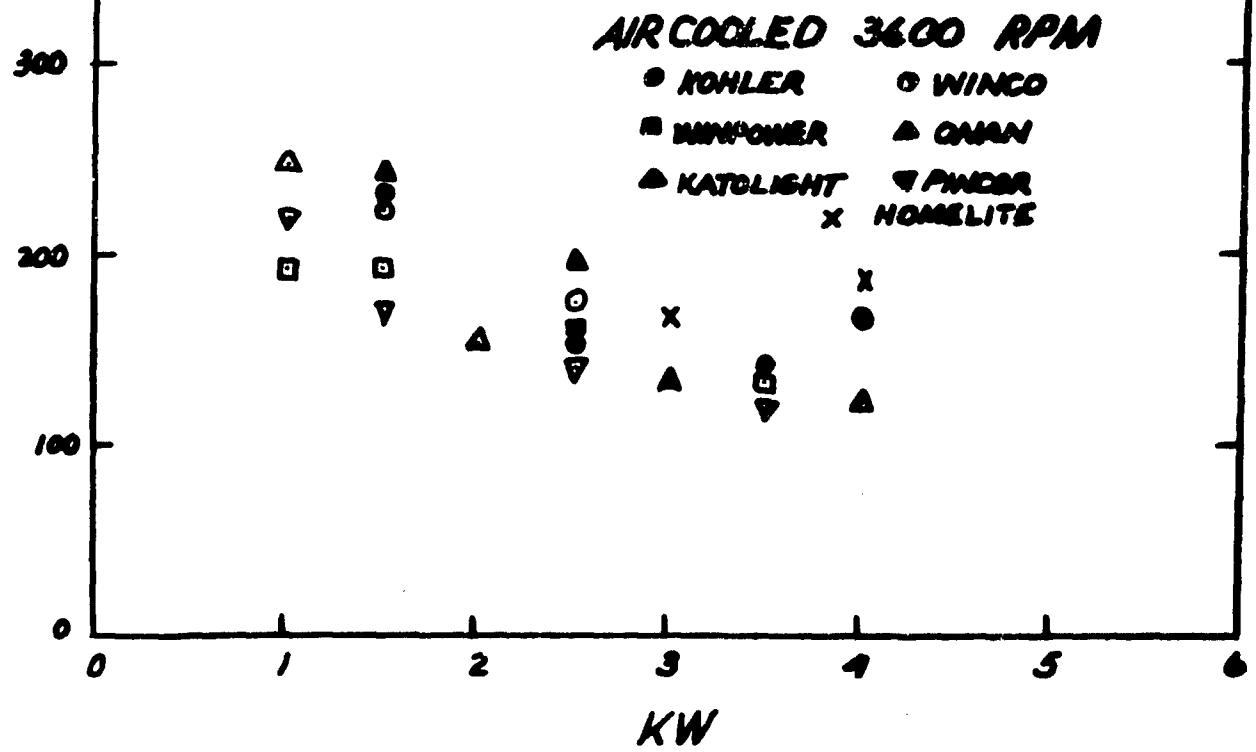
FIG. A7 INITIAL COST & FUEL RATE OF GASOLINE UNITS (3600)

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d. Operating characteristics

Engine-generator sets must be exercised during
the 10-year stand-by period unless future
research results in more acceptable storage
techniques. The generally recommended
practice is to exercise weekly for one-half
hour under part load. There was unanimous
agreement in discussions with various engine
manufacturers that the length of the exercising
period should be one-half hour in order to in-
sure that the engine is thoroughly warmed up.
This prevents subsequent condensation which
could result in corrosion. One or two manu-
facturers suggested longer time periods
between exercising, but the weekly period was
generally considered best from the standpoint
of engine starting. However, carbon deposits
in the cylinder caused by frequent light-load
operation would be lessened and thus the chance
of engine malfunction reduced if exercising
were less frequent. If the engine is properly
exercised, the carbon build-up factor would not
be a valid consideration for less frequent
exercising. In view of the accepted procedure
of weekly exercising, which has been proven in
practice, and lack of data on how effectively
less frequent exercising would control carbon
deposits for 10 years, weekly exercising under
part load is recommended.

The sturdy, heavy-duty engines allow weekly
exercising. The LPG-fueled engines should
be exercised at 50 per cent rated load and
gasoline-fueled engines should be exercised
at 90 per cent of rated load since LPG is a
cleaner burning fuel.

It is recommended that engines be operated at
80 per cent of rated load during the three week
emergency period. Three reasons for this
recommendation are as follows:

(1) The reserve capacity will provide a safety
factor to allow for additional load and reduce the
likelihood of engine failure

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AIR COOLED   GASOLINE   1800 RPM.

○ KOHLER   ● WINCO
□ WINPOWER   ▲ ONAN

▲ KATOLK 1T

POUNDS OF FUEL PER KWH

KW

AIR COOLED   DIESEL   1800 RPM.

○ ONAN   ▽ AMERICAN MARC
□ WINPOWER   ● WITTE
▲ KOHLER

POUNDS OF FUEL PER KWH

KW
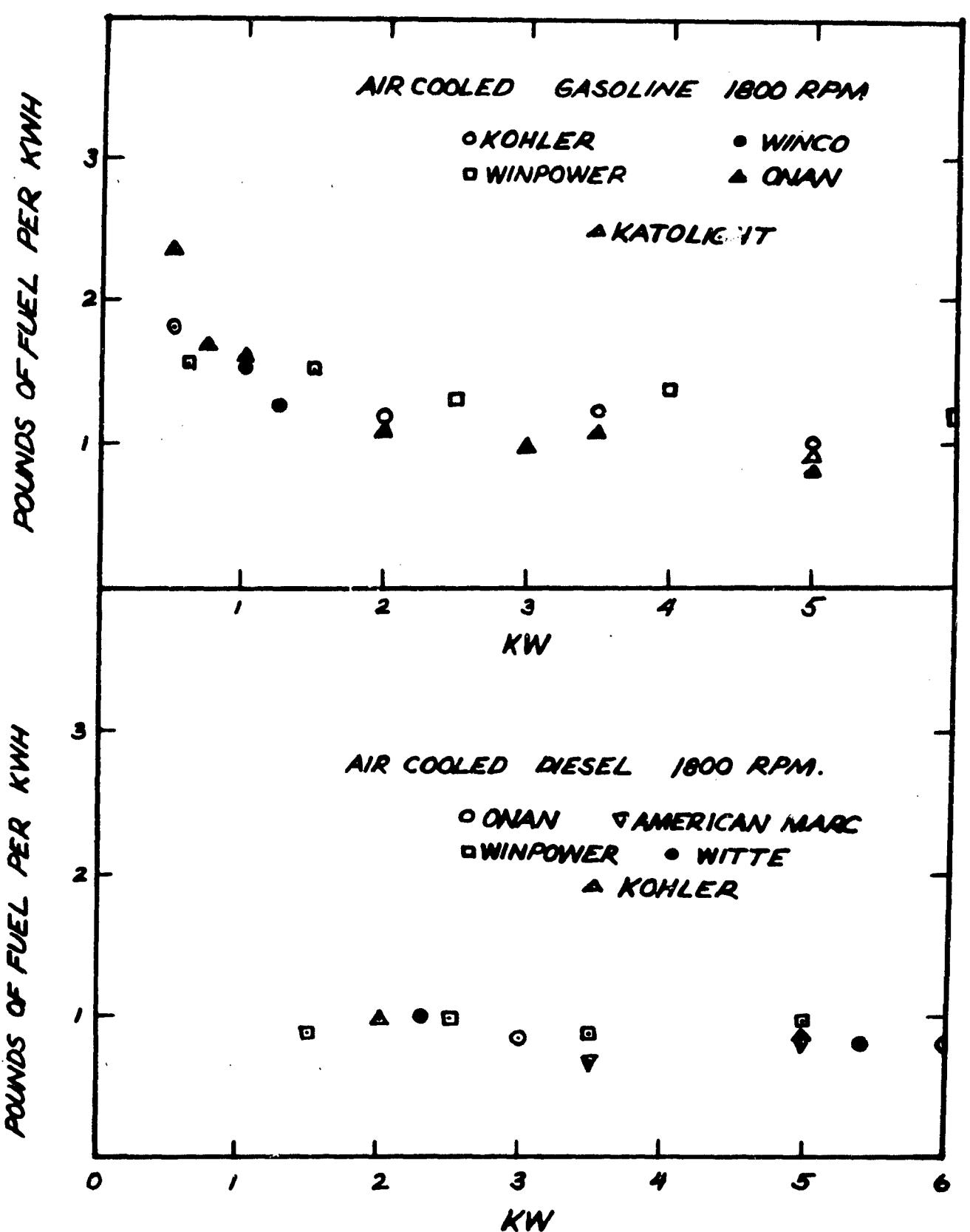
FIG. A8   FUEL RATE OF GASOLINE & DIESEL UNITS (1800 RPM)

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(2) The lower bearing pressures, lower operating temperature, and other factors will increase life expectancy of the engine.

(3) Carbon-deposit build-up in three weeks of continuous operation should not be significantly different at 80 per cent load than that expected at full load.

e. Fuel

Possible fuels for reciprocating, spark-ignition engines are natural gas, gasoline, LP gas, and producer gas generated from solid carbon fuels. Natural gas is predominately methane and thus would be stored as a gas unless cryogenic refrigeration equipment was utilized. This requirement is due to the fact that the critical temperature (above which liquefaction is impossible at any pressure) is - 116°F for methane. Since high-pressure vessels and refrigeration equipment are expensive, natural gas is eliminated from consideration.

Gasoline is the most common of the spark-ignition-engine fuels and is a mixture of hydrocarbons. The composition is varied seasonally to compromise between the ease of starting the engine and hot operating characteristics such as vapor-lock and fuel loss by evaporation.

Rather than specifying a certain analysis, gasoline is more often analyzed on the basis of the amount of the various fractions that distill at various temperatures. A typical U. S. Government specification requires less than 0.1 per cent surfur and the following per-cent-distillation-temperature relationship:

Temperature (F)	Minimum per cent distilled (including losses)
167	10
284	50
392	90

The maximum residual should be two per cent.

An average composition would be 83.5 to 85 per cent carbon, 15.0 to 15.8 per cent hydrogen, and 0 to 1 per cent nitrogen and sulfur. Its heating value is about 20,000 Btu/lb. The specific gravity is from 0.7 to 0.75.

Gasoline is more flammable than fuel oil, and consequently it is more of a fire hazard. While a gasoline engine has a slightly better engine starting characteristic than a Diesel engine at room temperature, it has distinctly better starting characteristics at less than 32°F. The assumed initial shelter temperature (45°F) is in an indeterminate region and small Diesel engines may require ether capsules or other starting means, while the spark-ignition engine should start without such aids.

LP gas is essentially liquified propane and butane. It has a heating value of approximately 21,000 Btu/lb and a specific gravity of 0.54 (reference A2). It is stored as a liquid and vaporized for use.

Producer gas is formed just prior to utilization from solid fuels by burning the material in only limited oxygen to produce a gas consisting essentially of carbon monoxide, hydrogen, and nitrogen. The heating value per cubic foot is lower than LPG and modification of the engine is necessary in order to obtain the same output. This does offer an opportunity to utilize easily stored solid fuels for use with an internal-combustion engine.

3. Gas Turbines

   a. Availability

   Gas turbines in the 30 horsepower and larger sizes are in operation. Various large units have been installed and are functioning satisfactorily

for commercial and industrial purposes. However, no turbine-driven generators have been built in the range that even approach the five KVA maximum power output of this study.

b. Operating characteristics

Thermodynamic analysis of these units shows that as the size of the unit is decreased, the wheel speed of the turbine must increase to maintain a practical efficiency. The limitations of the strength of materials and high fluid friction prohibit considering these units for the five KVA power supply in the shelter application.

c. Fuel

These units use the same fuel as the Diesel engine.

B. Storage of Internal-Combustion Engines

The storage procedures for internal-combustion engines are divided into three categories for the purposes of this discussion: (1) shelf storage, (2) "moth-ball" storage, and (3) exercising. These three types of storage are defined as follows:

1. Shelf storage is storage of the set as a unit at an engine distributor's warehouse, storage in the stock room of a manufacturer, or delivery to a shelter and storage in the original carton.

2. Moth-ball storage is the type of storage that one might expect in "moth-balling" of used military equipment for future use and often involves disassembly and special preservation of subcomponents.

3. "Exercising" is a procedure whereby the engine is installed and made ready for operation. The engine is then operated periodically over the time interval that it is to be "stored".

The last of these methods was unanimously recommended
by all engine and engine-generator-set manufacturers
that were contacted. There are valid reasons for this;
a detailed discussion of each of the procedures follows:

1. Shelf Storage

   The storage of engines in their original crating and/or
   carton is feasible for several years under fairly good
   storage conditions (primarily elimination of moisture).
   However, even under the best storage conditions it
   is questionable whether or not the unit would function
   satisfactorily without maintenance before use after
   10 years storage. It is expected that in many instal-
   lations the unit would not function due to oxidation and
   corrosion. The ability of the engine to function after
   a ten-year shelf life could be checked by control tests
   and a statistical evaluation of results, but one draw-
   back discredits this means of storage and renders the
   test unnecessary. The drawback is that the engine is
   first installed and utilized at the time of the emergency.
   First runs on new installations have a high probability
   of requiring at least minor adjustments on the power
   supply system that cannot be corrected without
   experienced personnel and the proper equipment.

   The following precautions should be considered in
   attempts to provide satisfactory shelf storage:

   a. The final engine "break-in" would be with an oil
      containing a vapor-phase inhibitor to protect the
      interior surfaces from corrosion.

   b. The engine-generator set would be wrapped or
      sealed in a moisture-barrier material in such a
      manner that the barrier would not be damaged or
      broken in handling during shipment.

      A crate protecting a carton, with instructions to
      refuse to accept any crates containing damaged
      cartons, is one method of guarding against a
      damaged moisture barrier. The purchase order
      for the engine-generator set would include per-
      mission to refuse acceptance of units received
      with damaged cartons.

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c. A container of desiccant would be placed within
the carton to absorb moisture. An available
material that changes color when saturated
could be placed near a cellophane window in the
moisture barrier. If the color change indicated
saturation, the desiccant would be replaced.

It is anticipated that the above procedure would result
in formation of a thin film of copper oxide on the
generator collector rings, but this could be removed
by holding a low-cost seater stone against the rings
for a few revolutions of the generator shaft. Including
these stones in the engine-generator-set shipment
has been used in the past and the procedure is effective.
The magneto points might have to be cleaned with emery
cloth.

While there is insufficient data to show whether or
not a vapor phase inhibitor would protect the cylinder
of the engine for 10 years, additional research is not
suggested for this untried method to guarantee 10-year
storage. Again the main disadvantage of such a
storage procedure is that the engine-generator set
cannot be tested after installation to insure that the
over-all power-generation system is functioning
satisfactorily. Unsatisfactory industrial experience
with starting equipment for the first time provides
sufficient reason to eliminate this method as a
storage procedure.

2. Moth-balling

Moth-balling is a procedure in which the equipment
would be installed and tested under actual operating
conditions and then would be partially disassembled
and repackaged for optimum shelf life. This procedure
would eliminate the "first starting" objection of the
shelf-storage method. The success of a moth-balling
procedure would depend upon the ability of the instal-
lation personnel to moth-ball the equipment and the
shelter personnel to put the equipment back into
operation. Trained personnel with the proper tools
could assemble an engine-generator set from individual
components that had been individually packaged to pro-
tect all unpainted surfaces from corrosion.

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A suggested moth-balling procedure would be that the
generator be packaged as a unit and, for the best
protection against the ten-year-storage effects, the
engine be as least partially disassembled for applying
and removing protective coating from the pistons,
cylinders, and other unpainted surfaces. The car-
buretor and the magneto could be stored as sub-
assemblies, provided they were removable. Retention
of residual magnetism is discussed later. The storage
of the generator (except for demagnetization) is not a
problem, and engines have been rejuvenated after 10
year storage by experienced personnel.

There are possible schemes for moth-balling that
would require less experienced personnel. These
methods include such procedures as hermetically
sealing the unit in a well-constructed, inert-gas-filled
chamber, but some mechanical ability would still be
required on the part of shelter personnel to connect
the fuel line, exhaust pipe, etc. A stripped thread,
broken bolt, kinked fuel line, or other damage due to
nervous, unskilled personnel might render the unit
unusable. In addition to moth-balling of the engine-
generator set, the other equipment in the power
system would have to be moth-balled. This additional
moth-balling would not have to be technologically as
complicated as for the engine-generator sets, but
factors such as keeping insects out of motors and
mildew off equipment would have to be considered.

The main objection to moth-balling procedures is that
unless skilled personnel are available during the
emergency, current moth-balling procedures would
have to be revised to simplify restoring the equipment
to active duty. These novel modifications have not
been tried nor proven by field experience.

3. Exercising

Exercising is a procedure by which the engine is
operated under partial load for a short period (one
half hour for this application) and placed on stand-by
duty without operation for a period of time (a week
is recommended for this application). This practice

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is commonly followed for keeping engine-generator sets in good operating condition and was recommended by all engine and engine-generator-set manufacturers interviewed. The advantages of this practice are:

a. The set is tested on location by qualified technicians to insure that the power system is functioning satisfactorily.

b. The weekly operation of the equipment is a positive test that the set is ready to operate when needed.

c. Operation of the set removes the copper-oxide film on the collector rings of the generator and thereby eliminates the need for cleaning of these components when the emergency occurs.

d. The cylinder walls are repeatedly covered by a new film of oil to prevent corrosion.

e. The pole laminations (if not permanent magnets) would be remagnetized weekly to insure that they would not lose their residual magnetism. If the poles lost residual magnetism, the magneto and generator would not function.

f. The use of soft-iron electromagnets would eliminate the need for permanent magnets. Some manufacturers believed that permanent magnets would remain at full magnetic strength for 10 years, but factual data are missing. Permanent magnets without a satisfactory "keeper", such as is the case of some magnets when installed in a generator, demagnetize with time. Generator operation also tends to demagnetize permanent magnets.

The disadvantages of exercising are:

a. The weekly exercising requires fuel. In 10 years the engine-generator set would run 260 hours as compared with the required 504 hours operating life for a continuous three week period of operation.

The fuel requirement for the entire exercising
period may be computed from data presented
in Fig. A3. The requirement varies from 80 to
46 gallons per KW rating for the 0.5 KW and
5 KW machine respectively when gasoline is used
for fuel. Although the exercising load is similar,
the fuel requirement for a Diesel engine will be
lower than for a gasoline engine. The LPG require-
ments (one half load operation) are approximately
60 gallons per KW rating for either a 1 KW or
5 KW unit.

b. Some form of periodic inspection during the 10
year stand-by period would be required. The
frequency and extent of the inspection would be
determined by the degree of automation of the
system.

The disadvantage of reduction in engine life is partially
off-set by the fact that the heavy-duty engines have a
life expectancy of 1000 to 2000 hours of continuous
operation. The life for intermittent operation will be
shorter due to the greater wear rates during cold
starts. Available data strongly indicate that an
accelerated life test for engine evaluation could be
developed to evaluate whether or not the shelter appli-
cation requirements of an engine-generator set are met.
This test consists essentially of reducing the time
between exercising to about eight hours. The failure
of a properly exercised engine would more likely be
due to wear than to corrosion. This wear could be
evaluated at an accelerated rate as long as the time
interval between operating periods allows thorough
cooling of the engine.

The equipment for automated exercising is discussed
below. The engine must be started, have a load
applied, have the load removed, and then stopped.
Various combinations of exercising equipment that could
be used in a shelter become apparent from a description
of the equipment.

a. Running-time meter - A timing clock records the
total time an engine has operated. This serves

as an indication of how frequently the engine operated and also shows when an oil change is necessary. This clock costs less than $30.00. One source of such a clock is the Onan Division of Studebaker Packard Corp., Minneapolis, Minn.

b. Exerciser Time Clock, a one-half-hour timer, automatically shuts down the equipment and eliminates the need for personnel to wait for one-half hour before stopping the equipment. The timer cost would be less than $35.00. A source of such a timer is Onan.

c. An Automatic Starter. - This would electrically start and stop the engine-generator set. An automatic starter would cost less than $110.00. One source is Katolight Corp., Mankato, Minn.

d. Sequencing Control - This control, which could be used for the emergency period as well as during the exercising period, would automatically apply a load to the equipment in such a manner that the engine generator set would not be overloaded by motor starting. A factor to consider in deciding whether or not to utilize this equipment is that the larger motors may supply torque to their loads through a clutch. This clutch would also have to be automatic if these motors were part of the exercising load. The cost of a sequencing control varies with the size of the set. A control for a 4 KW set costs $265.00; one source is Wincharger Corp., subsidiary of Zenith Radio Corp., Sioux City, Iowa.

The listed automatic equipment could be replaced by the following manual operations and/or simplified equipment:

a. Personnel could record the running time of the equipment and stop the equipment at the end of the exercising period. This would eliminate the need for the exerciser-time clock and running-time meter.

b. A starting rope could be used to start the engine instead of the automatic starter.

c. A series of switches could be turned on in the proper sequence instead of using a sequencing control.

The exercising procedure appears the most reliable, has the most field-operation background (for example, most automobile engines are operated for 10 years with intermittent duty), and is used and recommended by all of the engine and engine-generator-set manufacturers who were interviewed. Therefore, this is the recommended "storage" procedure for the shelter application.

C. Storage of Fuel for IC Engines

The successful storage of fuel (gasoline, liquified petroleum gas, or fuel oil) for the ten years required by the shelter application is a matter of speculation rather than fact. Conclusive data proving that these fuels can be successfully stored for 10 years is not available because the need for this long-storage characteristic has not been experienced in the past. Isolated cases of fuel having been stored for certain periods prior to use have been recorded, but the evidence is questionable. A more detailed study will soon be published by the U. S. Bureau of Mines.

The shelter application requires continuous operation of these engines for several weeks. This is a different situation than using a small tank or two of aged gasoline in an engine. The effects of utilization of aged gasoline is an accumulative process. Gum deposits accumulate to the point where they clog the carburetion system. The short-time use or intermittent use of aged fuels does not prove that the same aged fuel could be used continuously for several weeks.

Since factual data were missing, opinions were obtained. The opinions expressed below are on the basis that there exists evidence to show that the fuel will store satisfactorily for at least the following indicated times.

Longer storage periods might be satisfactory, but this would be speculation. These estimates are based on a storage system that does not contain copper, or zinc and the temperature is below 80°F. No other unusual precautions are assumed.

1. Conventional gasoline from the local gas station will store for six months. This is standard practice and not an estimate.

2. Conventional gasoline with special additives will store for one year.

3. Regular straight-run, aviation-type gasolines will store for one year.

4. Straight run gasolines with the addition of special additivies will store for two to five years.

5. No. 2 fuel oil will store for one year.

6. No. 1 fuel oil will store for two years.

7. Liquified petroleum fuel (L.P.G.) will store for five years.

8. Special additives plus very clean tanks might allow No. 1 fuel oil to store for five years.

This information is the basis for the recommendation that if there is insufficient time or funds available for further research, the fuels mentioned in items 1, 3, 6, or 7 above be stored in quantities that are consistent with the following procedure. The minimum quantity of fuel stored should be consistent with one-half-hour-weekly exercising for the above estimated storage life plus the operation during the period of utilization. The entire fuel supply should be replaced at the end of the recommended storage life. Table A2 presents the required fuel rates for typical engine-generator sets considered in this study.(A3).

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The use of a gas producer to generate producer gas is well known and has been used extensively on cars in Europe and Japan. The principle, incomplete oxidation of a solid fuel, could be accomplished by means of equipment for fuel storage and combustion presented later in this report for the Rankine-cycle turbine-alternator unit.

The anticipated efficiency of producer gas generation is 50 per cent. Final design of the unit and possible difficulties in use would have to be evaluated by experimentation. It would be an inconvenient means of providing fuel for weekly exercising.

Finally, it should be mentioned that LPG has a storage problem peculiar to itself in that provision must be made to vaporize the fuel prior to utilization. This may be accomplished by (1) flow of heat from earth to a buried tank, (2) flow of heat by convection from surrounding air to a tank in a fuel room, or (3) evaporation of the liquid prior to utilization in the engine by an exhaust heater or an engine-coolant heater. Recommendation for proper installation of LPG equipment is available from engine-generator set manufacturers and is discussed in detail in reference A4.

D. Heat Removal from IC Engines

1. Total Heat Rejection Requirements

The total required heat rejection rate, H_r (Btu/hr/KW rating), for continued operation of an internal-combustion engine can be computed from the specific fuel rate, FR (lb/kw-hr), and the heating value of the fuel, HV (Btu/lb). Since one kw-hr equals 3413 Btu, the total heat rejection rate would be

$$H_r = FR(HV) - 3413 \qquad A1)$$

2. Heat Rejection to Various Heat Sinks

This rejected heat would leave the engine-generator set as (a) heat content of the exhaust gases, (b) heat dissipated by the generator, and (c) heat dissipated by the engine. The quantities of heat dissipated by these various means may be determined.

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TABLE A2 Fuel Consumption Rates
for Continuous Duty

Generator Output (Watts)	Fuel Consumption (Pints/Hour)			
Air-Cooled, Gasoline	1/4 Load	1/2 Load	3/4 Load	Full Load
500	0.75	0.95	1.1	1.3
650	1.15	1.43	1.7	2.0
1000	1.7	1.9	2.2	2.4
1500	1.8	2.1	2.5	2.8
2000	2.1	2.8	3.3	3.7
3000	3.6	4.0	4.5	5.3
3500	3.6	4.7	5.7	6.4
5000	5.5	6.2	6.6	7.1
Liquid-Cooled, Gasoline				
500	1.7	1.9	2.2	2.4
2500	4.7	4.9	5.2	5.6
5000	4.9	5.9	6.8	7.6
Air-Cooled, LPG*				
1000	1.61	1.82	2.06	2.32
1500	2.12	2.38	2.92	3.18
2000	2.64	3.44	4.42	4.75
3000	3.97	5.02	5.56	5.82
3500	3.96	5.28	6.34	7.66
5000	7.66	8.72	10.05	11.6
Liquid-Cooled, LPG*				
2500	5.28	5.82	6.34	6.88
5000	6.08	6.88	7.67	9.53
Air-Cooled, Diesel				
2000	1.3	1.7	2.1	2.5
5000	2.7	3.2	3.8	4.9

*Based on catalog data and assuming 19,750 Btu per pound and 0.575 lb. per pint.

Milwaukee, Wisconsin

a. Heat removed by exhaust gases

This quantity can be computed approximately
by the following formula (assuming the air enters
at 90°F and the exhaust gas leaves at 1600°F):

$$H_{re} = M_a C_a \ (1600 - 90) \hspace{3cm} A2)$$

where H_{re} is the heat removal rate by the
exhaust gases (Btu/hr/KW rating)

M_a is the combustion air flow rate (lb/hr/KW rating)

C_a is the specific heat at constant pressure for
air (0.24 Btu/lb F)

All of the heat in the exhaust gas is not ejected by
mass flow from the shelter because the exhaust
gases heat the exhaust pipe, which in turn heats
the surrounding air. This may be minimuzed by
making a short exhaust connection from the engine
to the outside of the shelter and insulating the
exhaust pipe.

b. Heat dissipated by the generator

Since the rating of a generator is the output, W_o,
(KW) which is generated at some efficiency,
e (per cent), the generator heat that must be
rejected, H_{rg} (Btu/hr/KW rating), can be
determined quite readily. For a machine with any
KW rating this becomes simply

$$H_{rg} = 3413 \ (100 - e)/e \hspace{3cm} A3)$$

If more specific information is not available, a
generator efficiency of 70 per cent is reasonable
in the less-than-5-KVA machines.

c. Heat dissipated by the engine

The heat dissipated to the engine room and to
the engine cooling water (if water cooled) is
given by Eqs. A1, A2, and A3 as

$$H_{rc} = H_r - H_{re} - H_{rg} \hspace{3cm} A4)$$

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where H_{rc} is the heat removed from the engine by air or water cooling along with miscellaneous radiant and convective heat loss to the engine room, (Btu/hr/KW rating).

3. Sample Calculation

Assume that a 4 KW engine-generator set is using 60 lb of air per hr and uses 20,000 Btu/lb fuel at a specific fuel rate of 1 lb/kw-hr; the generator efficiency is 70 per cent. The following heat rejection rates may be easily computed.

Total heat rate $= 4 \left[(1.0) \ (20,000) - 3413 \right]$
$= 66,348$ Btu/hr

Exhaust-gas loss $= 60 \ (0.24) \ (1510)$
$= 21,760$ Btu/hr

Generator loss $= 4 \ (3413)(100 - 70) \ /70$
$= 5851$ Btu/hr

Engine cooling loss $= 66,348 - 21,760 - 5,851$
$= 38,737$ Btu/hr

When it is remembered that an average active adult dissipates only 600 Btu/hr, this simple example indicates that the cooling problems with even small engine-generator sets are important.

4. General Discussion of Heat Dissipation

a. Generator heat dissipation

While the actual rate of heat dissipation for any generator is given by Eq. A3, the generator efficiency will usually be between 65 and 75 per cent. Hence, it will be sufficiently accurate to assume that the generator efficiency is 70 per cent; this makes H_{rg} equal to 1463 Btu/hr/KW rating for all cases. The significant factor connected with this heat loss is that the generator windings must not be allowed to exceed 176°F unless

special insulation allows higher temperature operation. Thus the required mass flow rate of cooling air, M_c (lb/hr/KW rating), is related to the inlet air temperature, Ti, and the permissible outlet temperature, T_o. Using the First Law of Thermodynamics (conservation of energy) and tacitly invoking the Second Law of Thermodynamics (T_o must be less than 176°F), the value of M_c becomes

$$M_c = H_{rg}/C_a(T_o - T_i) = 6100/(T_o - T_i) \qquad A5)$$

Using Newton's Law of Cooling, a relationship between an over-all heat transfer coefficient, U (Btu/hr sq ft F), and a mean temperature difference between the generator surface and the cooling air, ΔT, is given as follows:

$$W_o H_{rg} = UA\Delta T \qquad Btu/hr \qquad A6)$$

where W_o is again the KW rating of the generator.

Manufacturers of small engine-generator sets usually give total air flow requirements for cooling the generator and the engine.

b. Engine heat dissipation by means of a radiator

If the engine is water cooled, the coolant should not enter the engine at a temperature of less than 140°F (A4). The trend of wear rates versus time after starting were recently reported (A5) and the results are shown in Fig. A9. These data show rapid wear rates shortly after starting the engine; this may be due in part to a cold engine (data were reproducible only with the engine thoroughly cooled) and in part due to the drainage of lubricating oil from the cylinder surfaces. This figure indicates that an accelerated-life-testing program may be possible if the most important factor in exercising is cylinder wear and not corrosion. The weekly one-half-hour exercising of a cold engine is definitely a severe requirement for long engine life.

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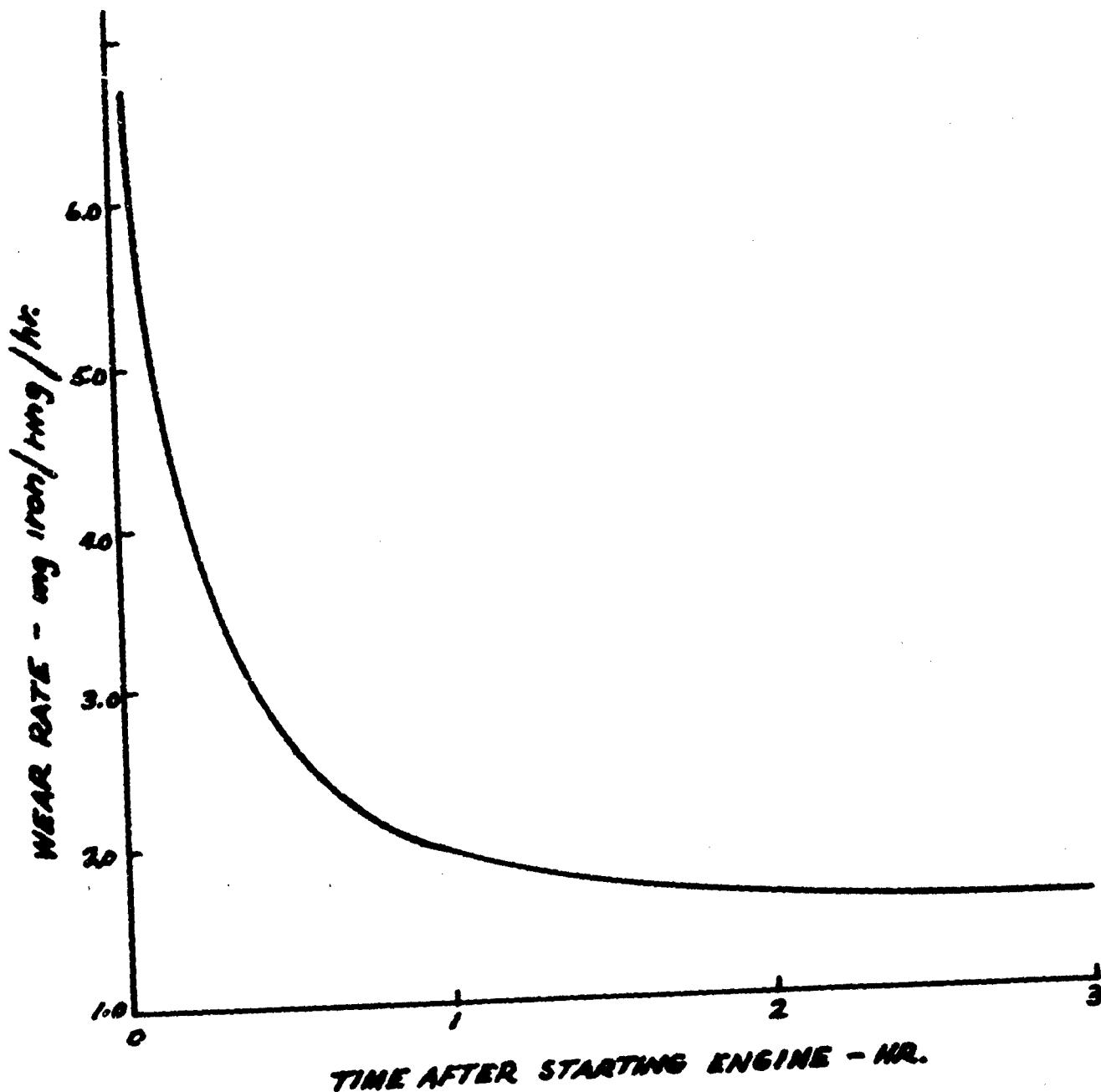
FIG. A9 WEAR CHARACTERISTICS OF
GASOLINE ENGINES

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The water should not leave the engine block above 180°F, for higher temperatures might result in local boiling within the engine. This boiling could cause scale deposits, which would impair the heat transfer and could result in local hot spots. Scale deposits could possibly clog water passages. If the engine is air cooled, the heat dissipation fins are probably around 375°F on the surface. Therefore, it can be reasoned that the boiling point of the coolant, not the engine characteristics, limit the water temperature.

Permanent antifreezes (ethylene glycol) have a high boiling point (387.5°F); but this direction (toward higher temperatures) is not a logical manner in which to proceed. Higher radiator temperatures cause the engine exterior to be hotter; this means more heat is transferred to the engine environment inside the shelter.

Air-cooled engines require large volumes of air to flow across the engine. The required rate varies nearly linearly with KW rating; a 5 KW unit requires approximately 700 CFM of atmospheric air. Outside surfaces of air-cooled engines must run hotter than is necessary for liquid-cooled engines because the poor heat transfer characteristics of air require a larger temperature difference.

c. Combined generator and engine heat dissipation

The generator and the engine can be cooled by using the same coolant in a series flow arrangement, provided that the temperature restrictions on the generator are satisfied. The heat transfer equations will usually be satisfied by combining these components for heat transfer calculations, but the operating temperature of the generator coolant should be checked to insure that the generator does not run too hot. Cooling air is normally passed over and through the generator and then over the engine

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to insure generator cooling and taking advantage of the high temperature finned surfaces on the engine to discharge the air at a higher temperature.

5. General Cooling Requirements

Regardless of the type of cooling system, certain requirements must be met as shown in Fig. A10. All heat removal means shown in the figure were previously described, but it will be convenient to consider the component of H_{rc} that is dissipated only to the engine room surroundings by convection and radiation. Let this component be represented by H_E (Btu/hr/KW rating). An estimate of the minimum heat loss from the engine to the shelter by this means will be investigated.

If the engine is a 1 ft by 1 ft by 2 ft rectangular parallelepiped (a minimum surface area), it would have an exposed surface area of 8 sq ft assuming that it is in contact with the floor on one surface. The surface coefficient of combined heat transfer, h_c, would be at least 4 Btu/hr sq ft F, and the average surface temperature (due to the 140°F minimum coolant restriction) would be at least 180°F. If the engine room environment is assumed to be not warmer than 110°F, then Newton's Law of cooling yields

$$H_E = hA\Delta T = 4 (8) (180-110) \qquad \qquad A7)$$
$$= 2240 \text{ Btu/hr}$$

The mass flow rate of available 90°F air, M_{ae} (lb/hr), required to remove this heat if a temperature rise of 20°F is permissible would be given as

$$M_{ae} = 2240/(0.24)(20) = 467 \text{ lb/hr} \qquad \qquad A8)$$

or 104 CFM. If the allowable temperature rise of the air must be reduced, the air flow rate required must be increased. It must also be remembered that the generator losses are transferred by cooling air.

S•Smith CORPORATION

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COOLANT (WATER OR AIR) AT $T \leqslant 180°F$

EXHAUST GASES

COOLANT (WATER OR AIR) AT $T < 140°F$

HEAT TO ENVIRONMENT H_E

ENGINE

GENERATOR

WORK

COOLANT (WATER OR AIR) AT $T \leqslant 140°F$

COMBUSTION AIR & FUEL

COOLANT (WATER OR AIR) AT $T \leqslant 100°F$
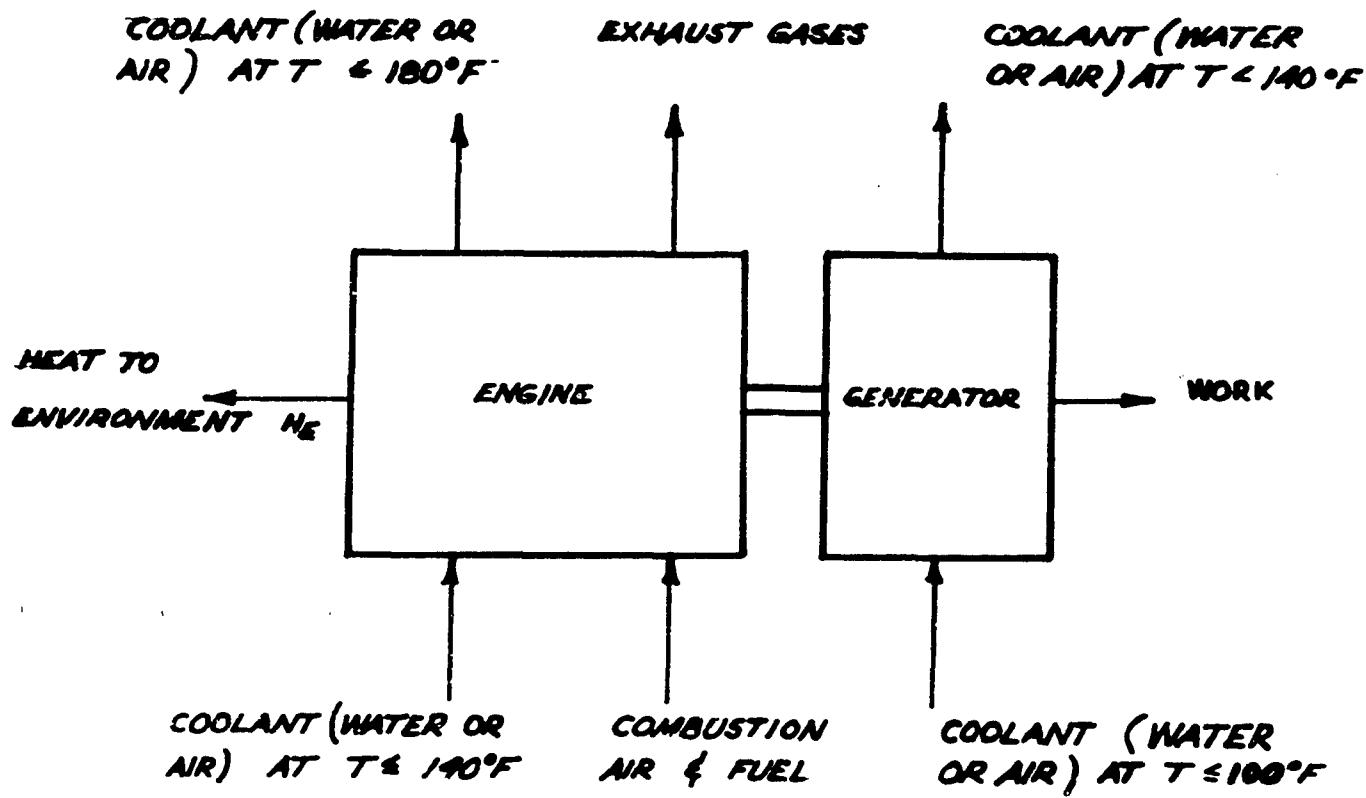
FIG. A10 COOLING REQUIREMENTS FOR ENGINE GENERATOR SETS

The conclusion arrived at from this analysis is that the engine-generator set should be isolated from the engine room. Methods must be developed to remove the engine and generator heat losses by some means other than using copious supplies of filtered shelter air.

6.   Methods for Cooling the Engine-Generator Set

Several methods of engine and generator cooling as well as noxious gas control are presented to demonstrate use of commercially available equipment. A "wind tunnel" arrangement is used in most cases to give the shelter designer an opportunity to purge any noxious gases from the engine with a minimum amount of air. If sufficient shelter air is exhausted directly into the engine room to cool the generator, remove engine radiation losses, and control noxious gas concentration, the "wind tunnel" concept would become unnecessary. Also a copious supply of exhausted shelter air would eliminate the need for a radiator to cool generator cooling air when well water is being used to cool the engine.

a.   Well water cooling

Figure A11 is an arrangement whereby water from a well or other convenient source is circulated through a radiator equipped with a thermostatically controlled valve, which is controlled by the temperature of the water in the mixing tank. When the water in the mixing tank rises above $160^{\circ}F$, the thermostatically controlled valve opens and allows cooler water from the radiator to flow into the mixing tank. When the temperature of the water in the tank has dropped to no lower than $140^{\circ}F$ as a minimum, this valve closes and stops the flow of the well water. The water in the mixing tank (at a temperature between $140-160^{\circ}F$) is pumped to the engine and in this manner cools the engine. The mixing tank is equipped with an overflow pipe which provides an outlet for excess water which can be used for waste heat applications or be discharged.

AIR TO OUTSIDE

ENGINE EXHAUST

AIR CIRCULATION

WATER FROM WELL

ENGINE   GENERATOR

AIR FROM SHELTER

RADIATOR

THERMOSTAT

MIXING TANK

PUMP

OVERFLOW WATER FOR WASTE HEAT APPLIANCES
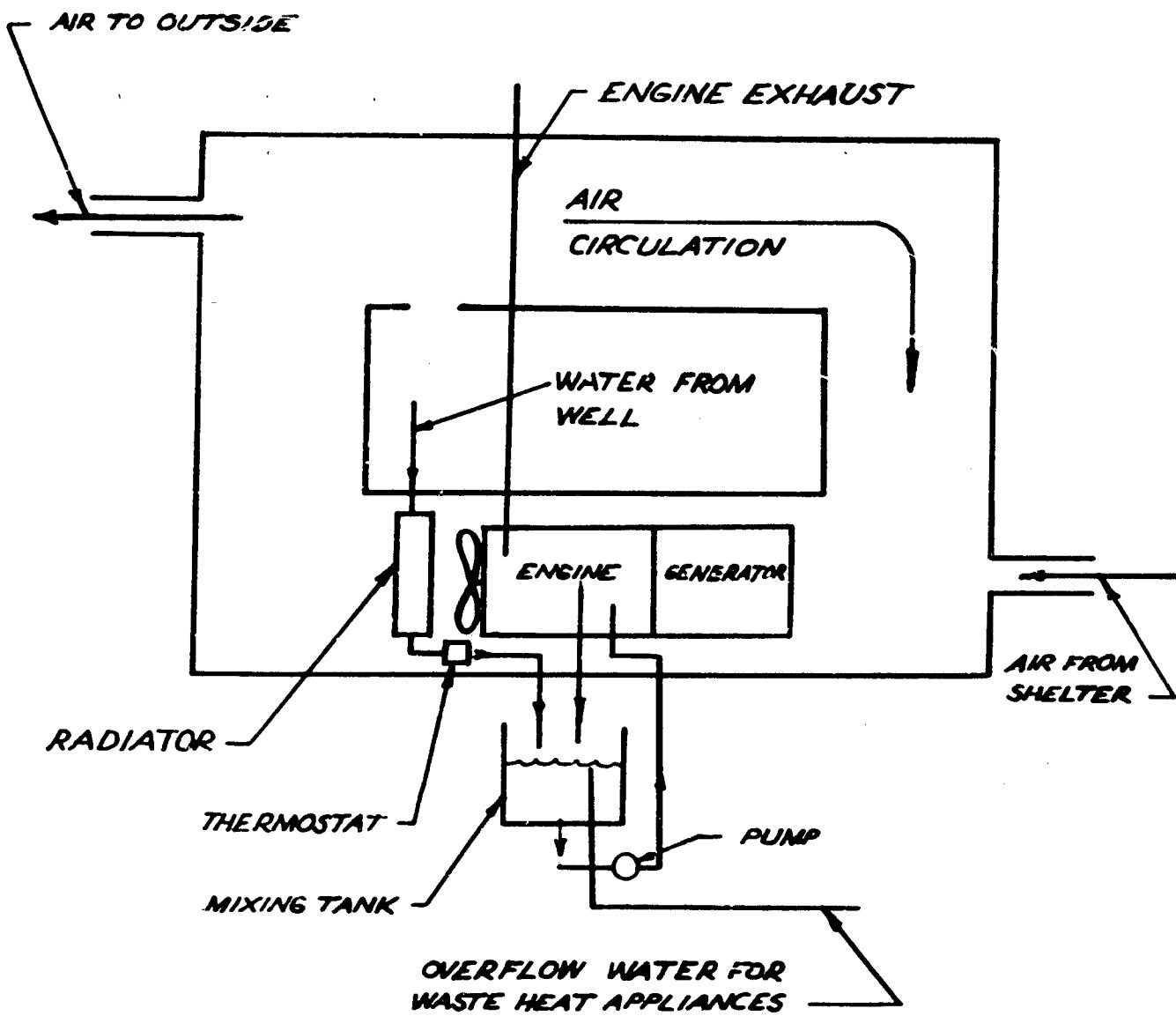
FIG A11   WELL WATER COOLING SYSTEM

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Excess air from the shelter is utilized in this arrangement to cool the engine-generator set and to provide combustion air. Some of the air is exhausted from the shelter and thus helps to remove noxious gases; the rest of the air that is not used by the engine for combustion is recirculated in the enclosure and acts as a circulated fluid for cooling the engine-generator set. Heat is removed from the air as it passes over the water-cooled radiator.

b. Contaminated-air direct cooling

The cooling of engine-generator sets in environments of contaminated air, where a supply of liquid coolants may not be available, suggests using the contaminated air for direct cooling with a suitable means for decontamination for servicing requirements. The reasons for this arrangement are:

(1) Although the engine can be liquid cooled by conventional procedures that allow the engine to be located below ground and its radiator to be located above ground, the generator is always air-cooled. This air-cooled generator is satisfactory for common usage of engine-generator sets, but using shelter air for cooling would give rise to a heat-dissipation-from-the-air problem or the need for large quantities of filtered cooling air.

Small generators are from 65 to 75 per cent efficient--thus every three kilowatts of electric power produced is accompanied by the liberation of a kilowatt of heat at the generator. As mentioned above, the required mass flow rate of air to reject heat from the generator alone is large and it is undesirable to reject a large percentage of the engine-generator heat using filtered air from the shelter.

(2) An objective is to prevent as far as possible any contamination of exposed engine and generator parts and thus minimize decontamination needs. In those areas where radiation from fallout would be acutely hazardous, particle sizes would be relatively large (greater than 40 microns). Hence the use of gravity separation and simple filters prior to the generator set could minimize contamination that must be eliminated in order to repair equipment.

(3) Many air-cooled engines, particularily those designed for outdoor utilization, could be washed down by a water spray without ill effects. Outdoor wiring is common, and welding generator sets for outdoor construction are common.

(4) Although the engine could use outside air for combustion, except for supercharging with momentary blast overpressures and heating intake air by nearby fires, it would be preferable to use purified shelter air and thereby restrict contamination to external parts. Also the combustion air requirement is quite small compared to cooling air needs.

(5) Considering the light weight fin and tube construction of radiators and the rugged fin construction of air-cooled engines, the entire air-cooled engine would be more resistant to a blast than the radiator of a liquid-cooled engine.

(6) In the opinion of many engine-generator set manufacturers and personnel associated with nuclear reactors, utilization of contaminated cooling air should not affect the engine-generator set operation.

In addition to the advantages of maintenance and heat dissipation from the generator mentioned above, the following advantages could be obtained from using the contaminated air for direct cooling the engine-generator set and for other purposes.

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(1) The fuel supply could be isolated from the shelter proper. Liquefied petroleum gas could be more readily used as a fuel without danger of contaminating the shelter air.

(2) The noise and odor accompanying engine-generator set operation would be isolated from the shelter proper.

(3) During the ten year standby period, the engine-generator set in the relatively small contaminated-air duct could be kept dry by a few strategically placed light bulbs to heat the surroundings and thereby cause any water to remain in the gaseous state; free circulation of air would remove the water vapor before water concentrations in the air would be such that condensation would occur.

(4) Lower cost air-cooled engine-generator sets could be utilized instead of the more expensive liquid-cooled systems. There are many more of these small size (5 KW and lower) units on the market than small size liquid-cooled units.

A suggested arrangement of a means for utilizing contaminated air for direct cooling an engine-generator set and providing combustion air for a water heater burner is shown in Fig. A12.

Contaminated air enters the engine compartment through a hooded duct (possibly equipped with a low cost dust filter), passes over the engine-generator set, is used in part for combustion in the burners and is rejected to the atmosphere.

In the event that service on the engine-generator set is required, two drop doors are closed on either side of the engine-generator set (purging of poisonous gas follows closure of one door) and the entire chamber and equipment between the doors is washed down by steam or water sprays.

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AIR FROM OUTSIDE

FILTER

CARBURETOR VENTED TO CRANKCASE

AIR FROM SHELTER FOR COMBUSTION IN ENGINE

AIR FROM SHELTER FOR PURGING AND BURNING WHILE MAINTAINING ENGINE-GENERATOR SET

DROP DOORS

SPRINKLER HEADS

ENGINE-GENERATOR SET

VALVE

SUMP FOR RADIOACTIVE WASH WATER

AIR TO OUTSIDE

BURNER CONTROLS

BURNER

APPROXIMATELY 4 FEET TO SHELTER FLOOR

FIG. A12 CONTAMINATED AIR COOLING SYSTEM

D-2711 Pem.

The radioactive liquid is collected in a sump for purification or discharge. The burners could continue to operate by using shelter air during the maintenance period.

After the necessary servicing has been done on the engine-generator set, the drop doors are raised and the engine is restarted. The oil should not be seriously contaminated since, as the figure shows, the crankcase is vented to the carburetor and shelter air is used for combustion.

The fact that radioactive dust concentration is a personnel hazard suggests that preventive measures should be taken to minimize the contamination that reaches the decontamination chamber. Of course, the passage is fitted with suitable covers and shields to prevent direct radiation from causing the chamber itself to become radioactive; the design should minimize the amount of radioactive dust that enters the chamber. This can be accomplished by a low-pressure-drop air filter in the contaminated air inlet duct. The engine blower characteristics (or auxiliary blower characteristics, if used) could be matched with the filter characteristics to permit the necessary air-cooling of the engine-generator set.

The filter could be positioned by remote control before starting the engine-generator set (presuming a blast had destroyed the outside electrical source and outside air was contaminated). Other possible plans would reinforce the filter supports or provide means for replacing filters by remote control.

A method for prevention of excessive contamination would be to vent the engine crankcase to the carburetor and use decontaminated air from the shelter for the engine combustion process. The use of shelter air for combustion would protect the interior of the engine from contamination and would eliminate the need for handling any surface not washed by the decontamination spray. The probability of a generator maintenance problem is very low.

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An inventory of spare · ·rts for the generator is probably not required. A sealed generator would be ideal but contamination of generator internals is no particular hazard because of their high degree of reliability.

c.   Recirculated-water cooling

Figure A13 is much the same, in some respects, as Figure A11. Air from the shelter enters the engine compartment where portions are used for combustion, for discharging noxious fumes and for recirculating to cool the engine and generator.

The generator is further cooled by water-filled coils which are wound around the generator housing. After passing through the coils on the generator, the water is pumped through a radiator and up to a cooling coil located in a duct with flowing contaminated outside air. In this way the heat which was transferred to the water from the generator and from the radiator is rejected to the atmospheric heat sink. Many of the methods for reducing contamination of the duct are identical to those mentioned above.

The engine block is primarily cooled by the water passing through it. Hot water (180°F) from the engine is pumped into a mixing tank where some heat is transferred to a heat exchanger; this cooler water (140-160°F) is returned to the engine and the cycle is repeated. The heat exchanger system mentioned above is equipped with a thermostatically controlled pump (controlled by the temperature of the water in the mixing tank) which only operates when the water in the mixing tank rises above 160°F.

Since the arrangement in Fig. A13 contains two separate closed systems for rejecting heat to the outside, some provision must be made to replenish any water that may be lost from the systems. A cylindrical container equipped with a funnel, pressure tight cap, and a hand-operated air pump can be used pneumatically to force water into the system

FIG. A13 RECIRCULATED WATER COOLING SYSTEM
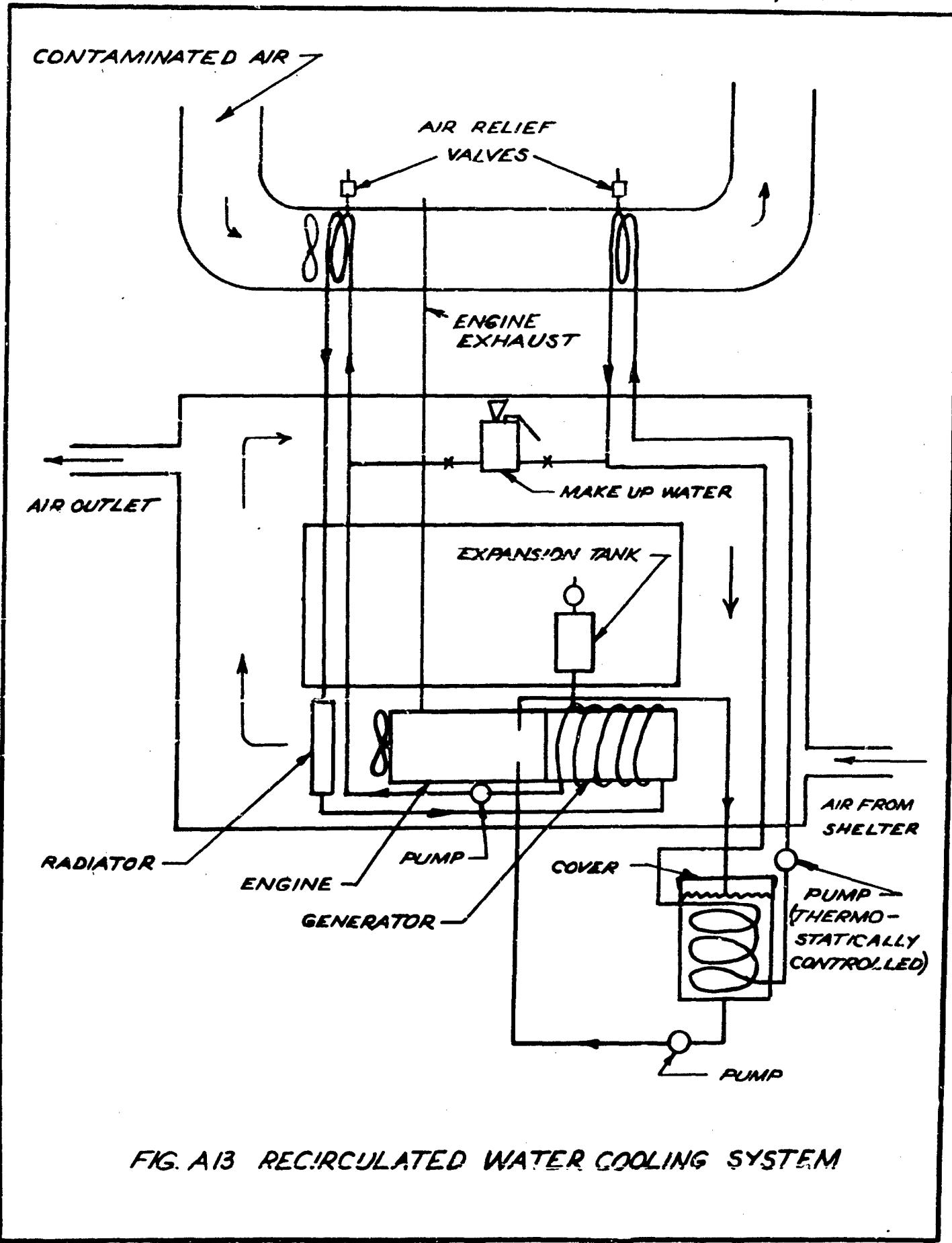
while the air-bleed valves at the highest point
in the system are open. The air-eliminator tanks
are installed to remove residual air during the
filling operation and air released while heating
the water.

d. Evaporative cooling

Figure A14 is essentially the same as
Fig. A13. The main difference is that in
Fig. A14 the rejection of heat is accomplished
through the evaporation of water as in a cooling
tower. If the containers which collect the
water in the contaminated air stream are acces-
sible for replenishing the supply due to leaks
and evaporation, no other equipment is re-
quired. If these storage tanks are inaccessible,
a method similar to that used previously can
be employed to pump water into the pipes.

E. Removal of Noxious Fumes from IC Engines

Internal combustion engines generate noxious fumes due
to the combustion process. Obnoxious fumes can be
generated from heating of the crankcase oil and evapora-
ting oil accidentally spilled on the exterior of the unit.

1. Exhaust Gas Removal

The combustion products need to be vented to the
outside atmosphere. Figure A15 is a diagrammatic
illustration showing a procedure for accomplishing
this exhaust gas removal.

The arrangement illustrated in Fig. A15 is a
standard recommended by nearly all engine
manufacturers.

A good exhaust system must be well supported
independently of the engine and connected to the
engine with a flexible metal connector made as a
continuous piece. It must be large enough in
diameter to reduce back pressure and arranged
so that water from rain and snow cannot enter.
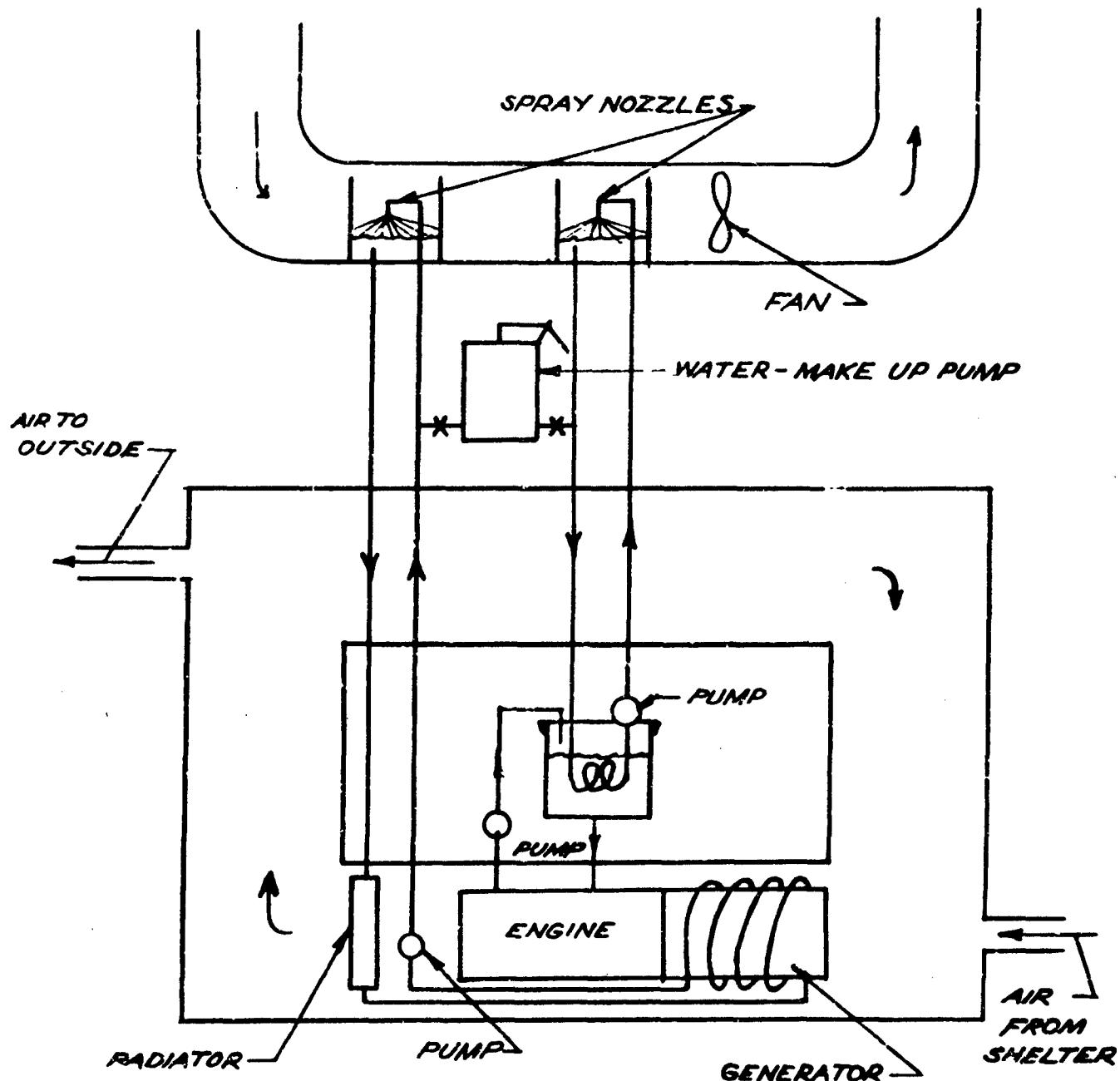
FIG. A14   EVAPORATIVE COOLING SYSTEM

SPRAY NOZZLES

FAN

WATER - MAKE UP PUMP

AIR TO OUTSIDE

PUMP

PUMP

ENGINE

RADIATOR

PUMP

GENERATOR

AIR FROM SHELTER

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HOLES TO PERMIT HEAT TRANSFER BY CONVECTION

EARTH OR CONCRETE

METAL THIMBLE PERMITS 6" OF AIR SPACE BETWEEN PIPE & THIMBLE. IT MUST EXTEND 9" ON EITHER SIDE OF COMBUSTIBLE MATERIAL.

SUPPORTS

PITCH EXHAUST PIPE SLIGHTLY TOWARD CONDENSATE DRAIN SO THAT CONDENSATE CANNOT ENTER THE ENGINE

MUFFLER

EXHAUST MANIFOLD

RIGID PIPE NIPPLE 6-8" LONG

FLEXIBLE CONNECTION

CONDENSATE DRAIN VALVE

FIG. A15 EXHAUST GAS REMOVAL SYSTEM

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It must also be gas tight. Where a vertical exhaust stack is necessary, as is assumed for a shelter, an alternative to bending the exhaust pipe outside of the shelter is to purchase commercially available rain caps for the exhaust stacks. Every provision must be made to minimize back pressure on an exhaust system. Some of the adverse effects of excessive back pressure are 1) loss of power, 2) poor fuel economy, 3) high combustion temperatures resulting in short service life, 4) jacket water overheating, and 5) crankcase sludging and corrosion or bearing damage. In order to minimize back pressure, exhaust pipes should be as short and straight as possible. Right angle bends should be kept to a minimum, and when used they must be of a radius four or five times the diameter of the pipe.

The muffler should be mounted as close as possible to the engine to keep it from rusting out, but it should never be directly connected to the exhaust manifold; this practice would put excessive stresses on the manifold and could cause it to fail.

NFPA recommendations (A6) require exhaust pipes which pass through combustible roofs be guarded at the point of passage by ventilated metal thimbles which extend not less than nine inches below roof construction. and which are 12 inches larger in diameter than the pipe. If double ventilated metal thimbles are used, the same requirements apply except that the thimble should be at least six inches larger in diameter than the pipe.

2. Obnoxious-Fumes Control

The fumes from the crankcase can be vented by piping the breather vents of the crankcase to the air intake of the carburetor. These fumes are then burned with the fuel or pass out of the shelter through the exhaust pipe. This breather tube from the crankcase to the air intake is standard equipment on some engine-generator sets. If the air surrounding the engine is not isolated from the air in the room, the

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breather tube should be considered an essential
component of the engine generator set in order to
prevent air contamination. It should be installed
by the manufacturer because it is a modification to
the set.

The utilization of oil in an engine usually results in
the spilling of some oil on the set. This oil will
evaporate or burn and contaminate the air surround-
ing the set. This contaminated air is automatically
isolated from the shelter in the heat-removal schemes
shown in Figs. A11 - A14. However, if such schemes
are not used, the engine generator set should be
located so that the air that has flowed past the engine
is not mixed with the engine room air supply.

If the engine-generator set is to be used in a small
enclosed chamber designed for preventing shelter
air contamination, the heat dissipation requirements
of the generator must be considered. This will
result in an enclosure similar to those shown in the
heat-dissipation methods in Figs. A11 - A13.

F. Control of Noise and Vibration From IC Engines

1. Mounting of Engine-Generator Sets

The mounting procedure for the installation of an
engine-generator set varies with each model and the
existing floor. The procedures for the various makes
are recommended by the set manufacturer and
distributors who should have experience with their
particular sets. These recommendations should be
adhered to and the installed set should be tested
before full payment is made.

The purpose of the special mounting procedure is to
prevent distortion of the engine-generator set com-
ponents during installation and, once installed , to
allow flexibility so that the set can vibrate freely, thus
ensuring that vibration is not propagated through the
surrounding structure. Objectionable noise could
result in addition to the stresses that would be
induced by vibration of the surrounding structure.

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A brief description of mounting prcedures included to familiarize the reader with the various techniques follows:

a. Semi-portable (temporary) mounting.

Some engines, particularly in the smaller sizes, are mounted on skids or slide rails. The nature of these mounting devices allows the engine-generator set to be dragged over relatively smooth surfaces without damage to the set. Skid-mounted engine-generator sets frequently require vibration dampers between the set proper and the skid (Fig. A16). Fig. A17 illustrates this mounting on a large unit (A7). The skids are set on concrete pads unless the floor is of unusually sturdy construction. If better sound-deadening characteristics are required, the concrete slab (which as a general rule is as heavy as the set) is mounted on a cork pad, which is commercially available for this application.

An alternative to the flexible mounting between the engine and a structural steel member that is set on the floor is the mounting procedure in which the set is bolted to a structural steel (or cast iron) base, which in turn is placed on springs or rubber vibration isolation pads. This procedure is shown in Fig. A18 and is suggested in reference A4.

b. Permanent Mountings

The permanent mounting procedures (A4) are similar to the semi-permanent procedures except that more elaborate precautions might be taken to eliminate propagation of vibration as shown in Fig. A19 and A20. The installation of the engine-generator set at a permanent location is accomplished by bolting the set to the base. The bolts are either accurately located or a "pipe sleeve" is employed.

Another procedure for permanent mounting would be to mount the engine-generator set on sole plates that are grouted (cemented) in place.
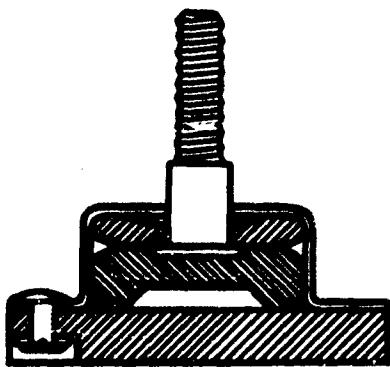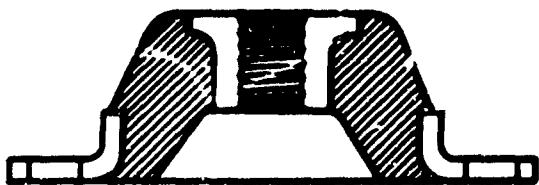
INTERLOCKING FEATURE
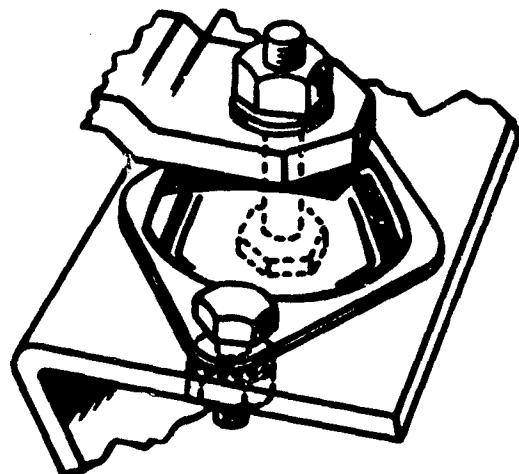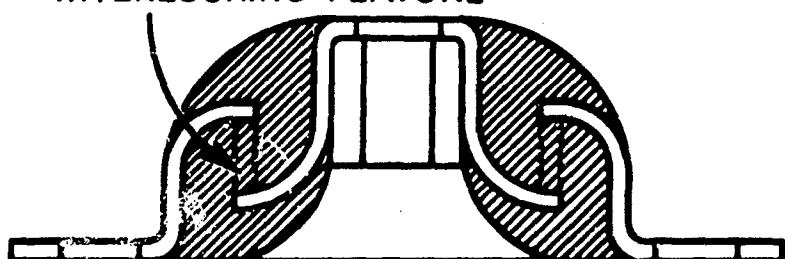
FIGURE A16   ENGINE VIBRATION ISOLATORS.

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**LOCATE PLANT BETWEEN
AIR INLET AND OUTLET OPENINGS**

**CONCRETE BLOCK
6" - 8" HIGH**

**VIBRO
DAMPERS**

SKID

**ALLOW AT LEAST
2' AROUND PLANT**
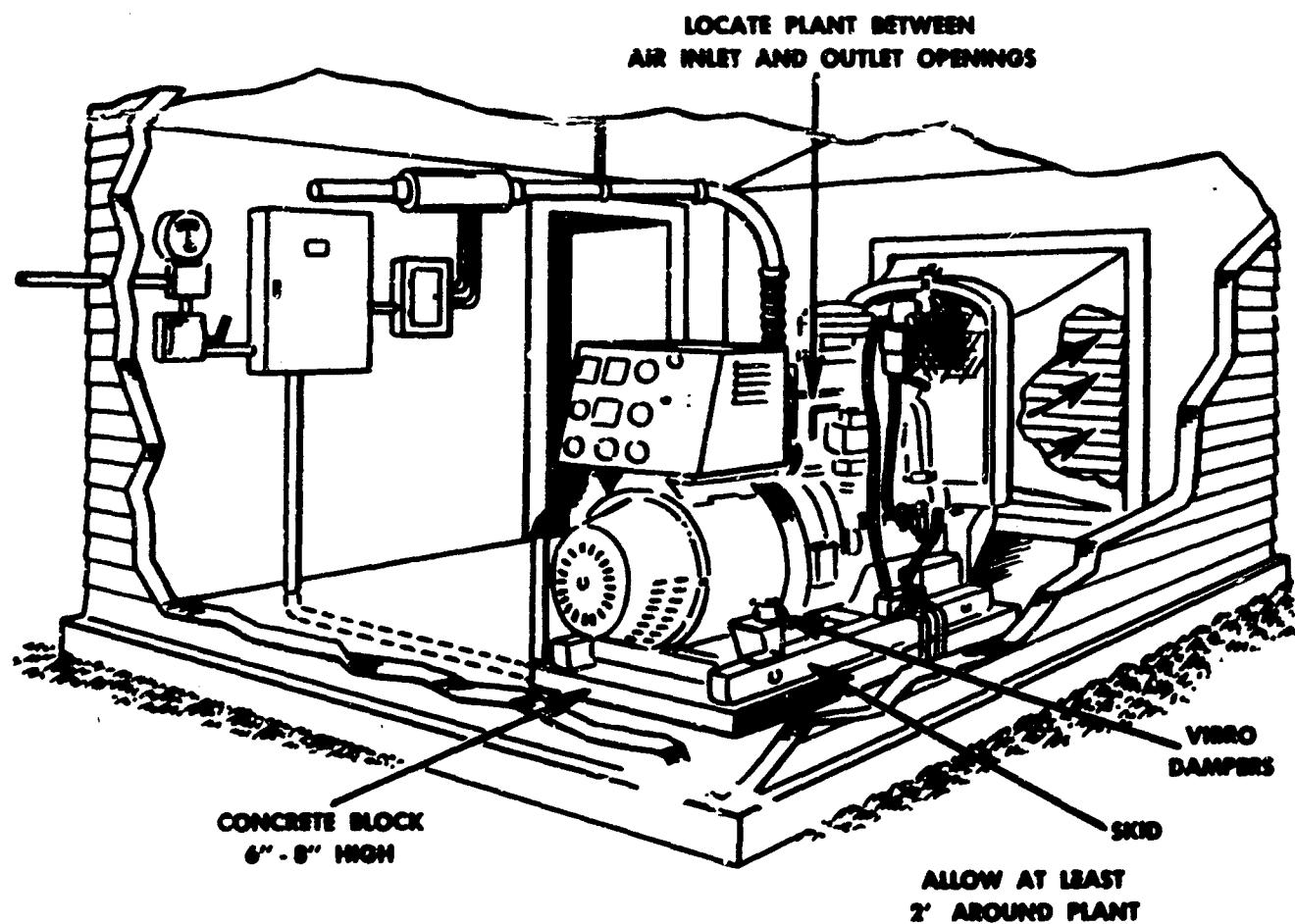
FIGURE A17   TEMPORARY FLEXIBLE-ENGINE-MOUNTING METHOD.

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COMMON BASE ALIGNS
ENGINE AND DRIVEN UNIT

VIBRATION
ISOLATING
PADS
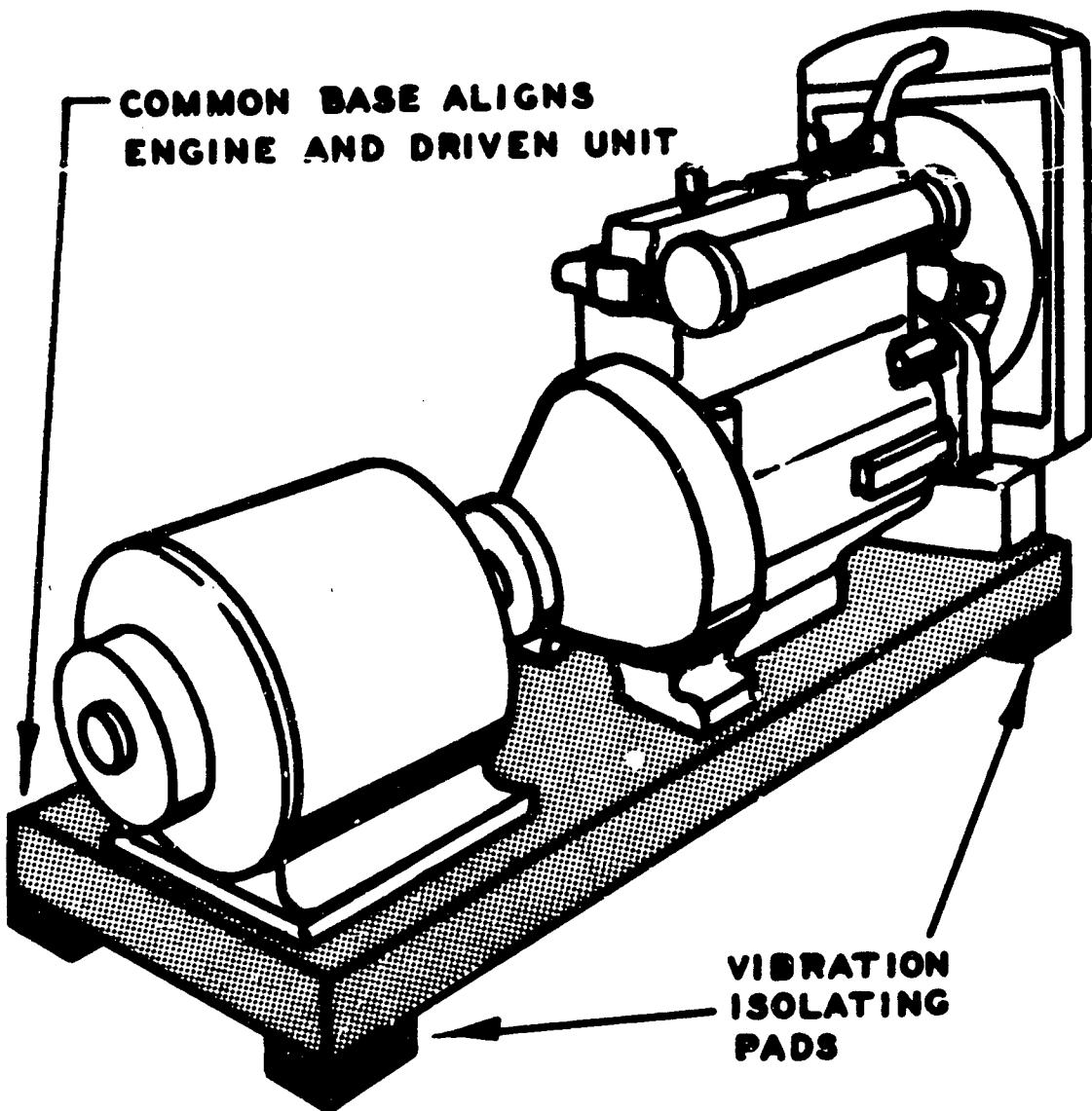
FIGURE A18   TEMPORARY RIGID-ENGINE-MOUNTING METHOD.

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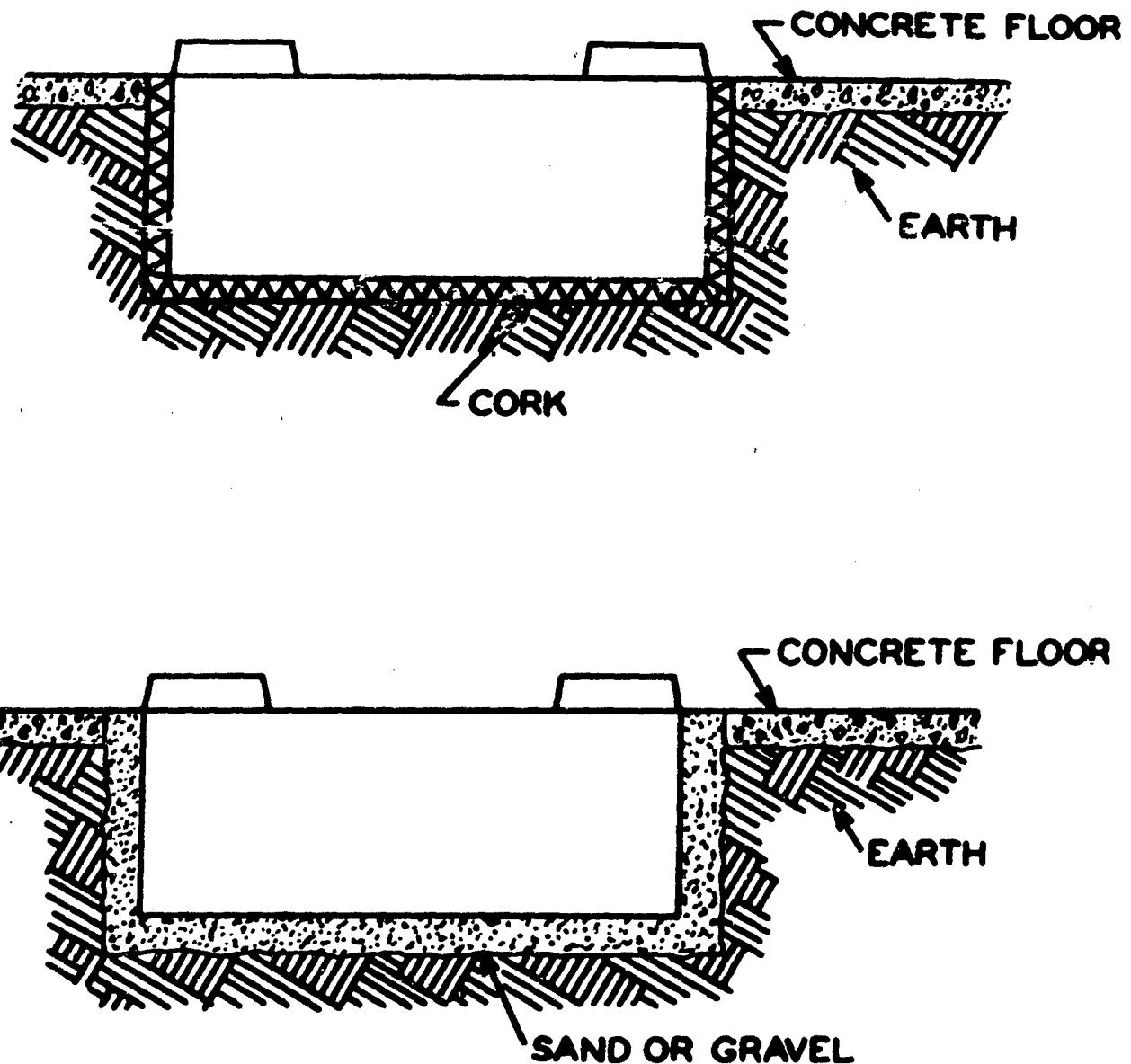
FIGURE A19   PERMANENT SMALL-ENGINE FOUNDATION.

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(CONCRETE SOLID TO BOLT)

CORK INSULATION

CONCRETE FLOOR

ANCHOR BOLT

FOUNDATION

PIPE SLEEVE

CORK INSULATION
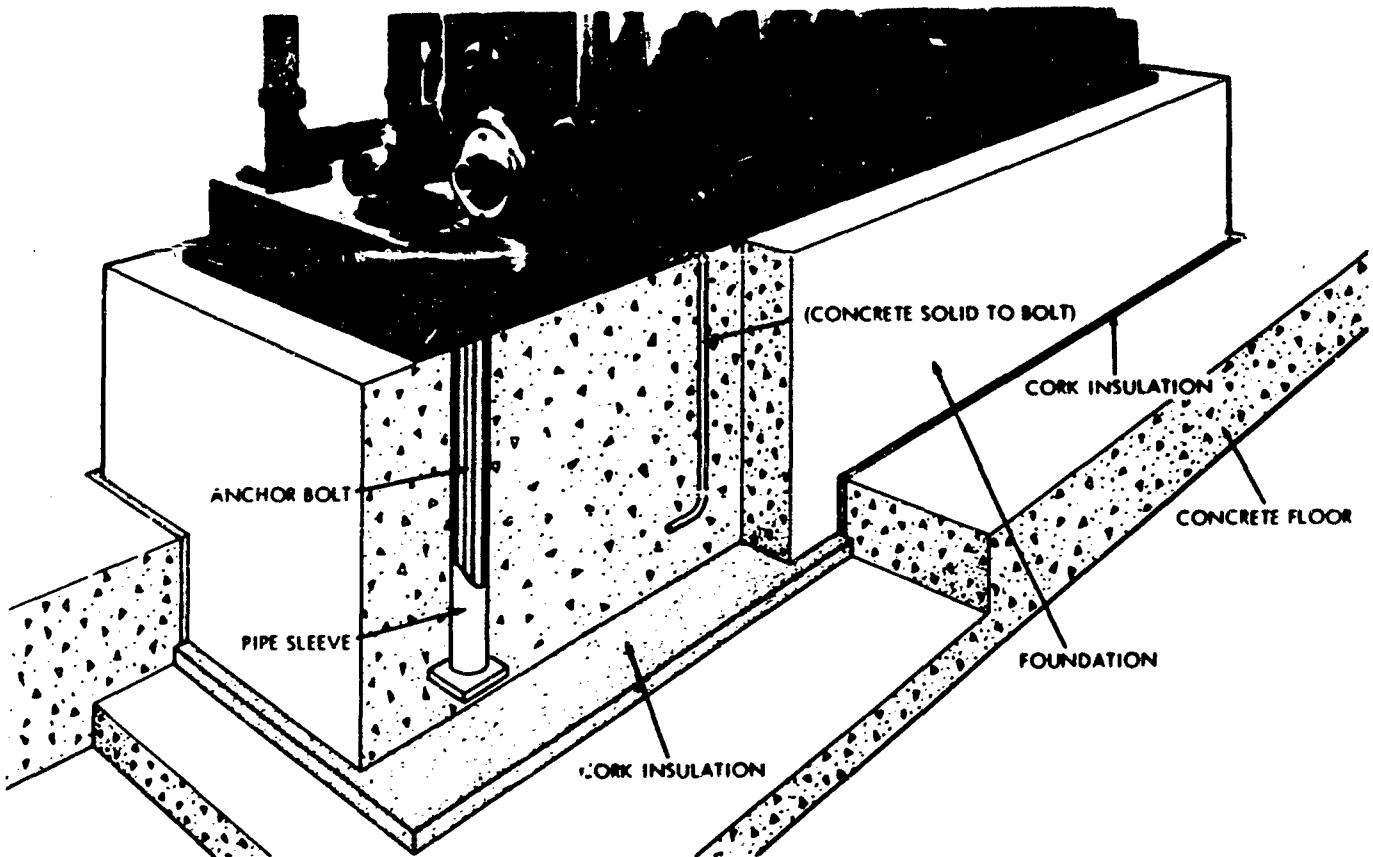
Rigid mounting, isolation of mounting foundation from building, allowance for error in anchor bolt placement, and a mounting foundation area greater than engine base area may be noted in this illustration.

FIGURE A20   PERMANENT LARGE-ENGINE FOUNDATION.

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This acceptable procedure requires flexible mounting between the set and the sole plates to prevent transmission of vibration to the floor.

c.   Portable mountings

Some small engine-generator sets are designed to be portable and the mounting equipment is included on the set. Figure A21 illustrates this method (reference A4).

d.   Miscellaneous mounting data

When the engine-generator set sub-base (concrete block, steel or iron base) is not placed on an existing structure of satisfactory load-bearing capacity, the information in Table A3 can be used to evaluate the safe bearing capacity of the ground (A4).

A factor that should not be over-looked at the time of designing the sub-base is that clearance (height above floor level) should be sufficient to allow the draining of crankcase oil and radiator water. Generally, this provision is met if the top of the sub-base is one foot above the floor level.

A distance of two feet between the set and the nearest fixed wall (wall that cannot be removed to facilitate engine repairs) is recommended by all manufacturers.

2.   Sound Passage Through Pipes

Vibration is readily transmitted along rigid pipes. This vibration transmission should be stopped as close to the engine as feasible. The pipe lines to the engine-generator set should have flexible connections. Bellows made as a continuous piece of metal should be used on the exhaust pipe since much unfavorable field experience has been encountered with the woven braid type. The flexible connections are commercially available from the engine-generator set manufacturer. The flexible connection should be located six to eight inches from the manifold for the exhaust pipe and immediately before the fuel pump (or first item solidly attached to the engine proper) for the fuel line.

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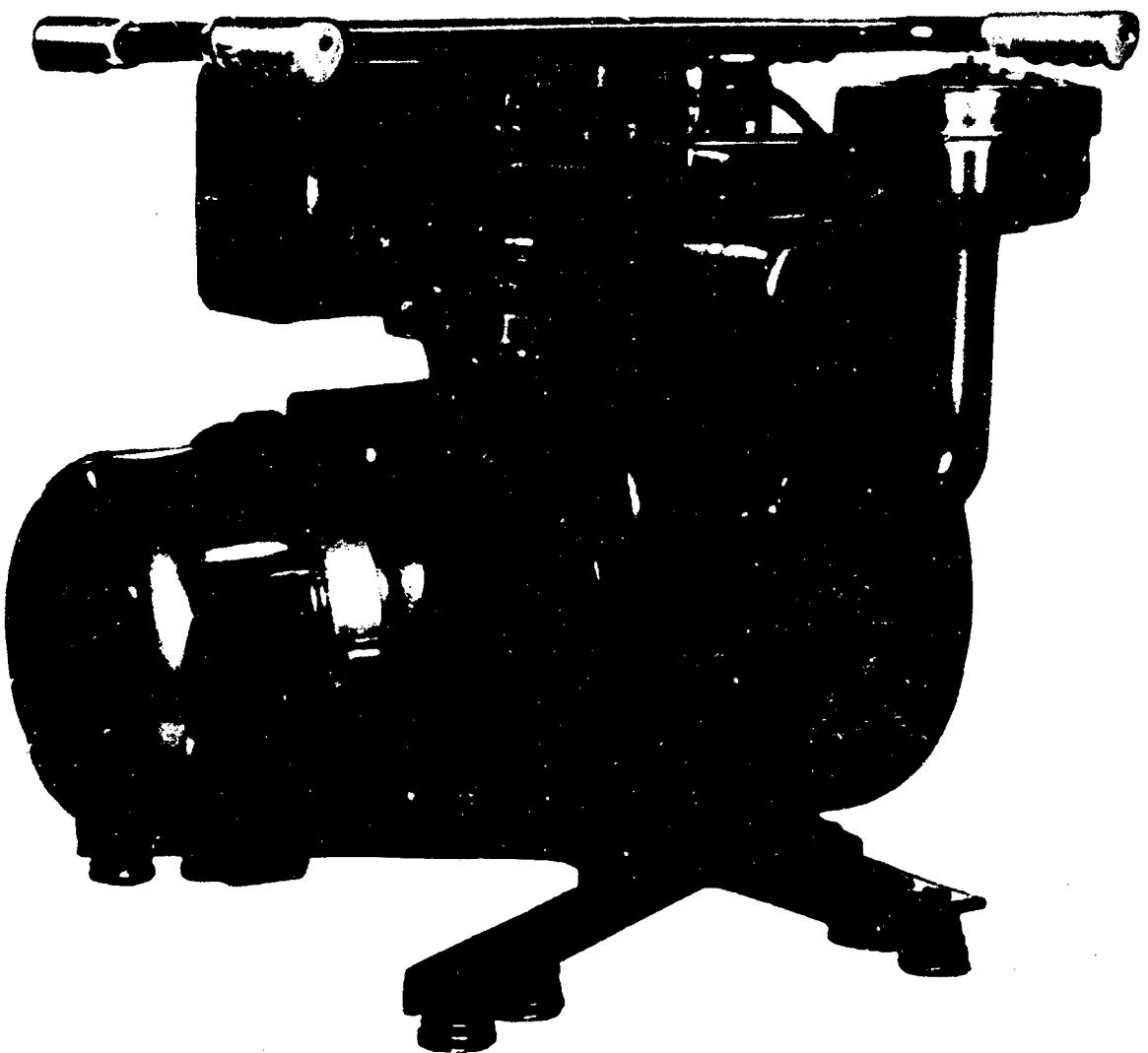
FIGURE A21   PORTABLE AIR-COOLED GENERATOR.

TABLE A3

LOAD-BEARING CAPACITY FOR
VARIOUS BEARING MATERIALS

Bearing Material	Safe Bearing Capacity (lbs/ft^2)
Hard rock - granite, etc.	50,000 - 200,000
Medium rock - shale, etc.	20,000 - 30,000
Hardpan	16,000 - 20,000
Soft rock	10,000 - 20,000
Compacted sand and gravel	10,000 - 12,000
Hard clay	8,000 - 10,000
Gravel and coarse sand	8,000 - 10,000
Loose, medium and coarse compacted fine sand	6,000 - 8,000
Loose fine sand	2,000 - 4,000
Soft clay	2,000

3. Sound Deadening Insulation

It is desirable to install the engine-generator set
in a chamber in the engine room. The chamber
should be thermally insulated and should not permit
engine fumes to contaminate the room air; also
sound deadening material (which is available from
many sources) can be used in the construction of
the isolation chamber. This would minimize
propagation of noise from the engine.

The sound deadening chamber should be so con-
structed that the flexible connections of the pipes are
on the interior of the chamber. The lower edge
of the sound deadening material should terminate at
the sub-base of the engine if the nature of the floor
allows sound transmission.

G. Recovery and Utilization of Waste Heat

Four important parameters to be considered in systems
designed to recover waste heat from an internal com-
bustion engine are (1) the quantity of waste heat available,
(2) temperature level of the waste heat compared to the
utilization temperature, (3) heat transfer coefficients
expected in the recovery equipment, and (4) permissible
pressure drop through the recovery equipment such that
engine performance is not affected.

The first parameter determines whether recovery is
economically justifiable, and the other three parameters
define equipment specifications. Table A4 gives typical
values for heat recovery in a small liquid-cooled engine-
generator set.

1. Liquid-cooled engine - circulating liquid

The systems presented in Figs. A11, A13 and A14
demonstrate cooling methods for liquid-cooled
engines in which all heat is dissipated to the environ-
ment. An obvious method of recovering waste heat
in the liquid would be to divert a portion of the flow
stream to an appliance for providing domestic hot
water, tempering ventilation air, etc. Also a part
of the waste heat in the exhaust gases can be recovered
at a higher temperature level (Table A4) to be used for
sterilizing equipment or even for high temperature
food preparation.

2. Liquid-cooled engine - ebullient liquid

Ebullient cooling has been a standard practice in oil-
test and knock-test engines for many years. This
cooling method consists of a liquid (usually water)
boiling in the coolant jacket and the vapor being
condensed on a remote cooling coil and the condensate
returning by gravity to the engine. The advantage
derived in standard test engines is precise control of
the engine coolant temperature. An important con-
sideration for the designer is that structural barriers
in the head passages must be avoided so that the vapor
bubbles may escape as rapidly as they are formed.

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TABLE A4

PARAMETERS IN WASTE HEAT UTILIZATION
(Liquid-cooled Engine)

Source	Quantity (Btu/hr/KW rating)	Available Temperature (F)	Heat Transfer Coefficient (Btu/hr sq ft F)	Available Pressure Drop* (in. water)
1. Exhaust gases	5,000	1200-1400	5-10	6.0 -10.0
2. Engine coolant (Standard pump)	5,000	140-180	50-2000	60-100
3. Generator Air Flow	1,400	120-140	5-10	0.75-1.5
4. Misc. Engine Cooling (Radiation, Environment)	5,000	110-120	1-5	0.25-1.0

*The shelter pressure is assumed to be 0.5 in. water gauge above atmospheric pressure. Exhaust gas and generator cooling air are discharged from shelter.

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Engineering Controls, Inc., St. Louis, Missouri has been an active proponent of ebullient cooling of large internal combustion engines (much above 45 hp) and has installed many waste heat recovery systems (Vapor Phase thermal circulation systems). The usual system consists of an elevated steam separator tank on a standpipe connected to the bottom of the engine coolant jacket. Circulation by thermosyphon principles occurs as the vapor formed in the engine passes through the steam seperator to be condensed and returned to the standpipe. The main advantages claimed are the self regulation of cooling, fluid circulation without a pump, and uniform cylinder head temperatures.

Although ebullient cooling and heat recovery equipment is generally unavailable for small engines, this system seems to be appropriate for shelter applications. Steam may be produced from the water coolant or from waste heat in the exhaust gases.

3. Air-cooled engines

It may be seen from Table A4 that the heat recovery potential from an air-cooled engine-generator set is low. The poor heat transfer coefficient at the engine head surface requires large quantities of cooling air and the waste heat is thus degraded to a low temperature suitable only for space heating, ventilation air tempering, and food warming. The exhaust gas heat recovery potential is identical to that of a liquid-cooled engine.

It was shown earlier that the majority of small engine-generator sets commercially available are air cooled. Thus a problem of supply (on an emergency basis) could favor heat recovery from exhaust gases, since this method is identical with either liquid-cooled or air-cooled units.

4. Utilization of Waste Heat for Cooking

Two types of cooking t¹ ... .re suitable for waste heat utilization are 1) low te . .rature warming and 2) high temperature baking. The engine coolant

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is obviously only satisfactory for warming because of
its low temperature, while the hot exhaust gases have
potential for higher temperatures for boiling and baking.
These two methods of cooking may be utilized for
individual servings or large batch cooking. However,
elaborate equipment most likely will not be used, since
the shelter is primarily for survival. Post-attack
conditions may warrant continued use of the shelter
as emergency quarters.

Several devices are described separately but combina-
tions are possible.

a.   Low-temperature, individual serving

Figure A22 represents a scheme for low-temperature
warming of individual servings. Water at approxi-
mately 180°F from the engine circulates through a
device similar to a steam table. After passing the
individual containers, the slightly cooler water passes
over the coils of a heat exchanger and then to the
mixing tank where it is pumped into the engine block
and repeats the cycle. The pump in the line to the
outside heat exchanger is thermostatically-controlled
by the temperature of the water entering the engine
block and is actuated when this temperature exceeds
160°F. If the temperature of the water entering the
block drops below 140°F, a manually controlled
valve can be opened allowing warmer water to reach
the mixing tank, thus increasing its temperature.
Also a manually-controlled bypass valve allows the
water to flow directly from the engine coolant outlet
to the mixing tank. This prevents excessive engine
cooling when very large quantities of food are
started to be heated.

The solution to the problem of maintaining water
in the line leading to the outside radiator is
identical to that shown in Fig. A13.

b.   Low-temperature, large-batch serving

If the food is to be warmed in a large container, the
small individual cans in Fig. A22 are replaced by a
large container. The design of the warming tank

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TO OUTSIDE RADIATOR

WARMING TANK

MANUALLY
CONTROLLED
VALVES

ENGINE
BLOCK

MIXING TANK

WATER
PUMP

THERMOMETER
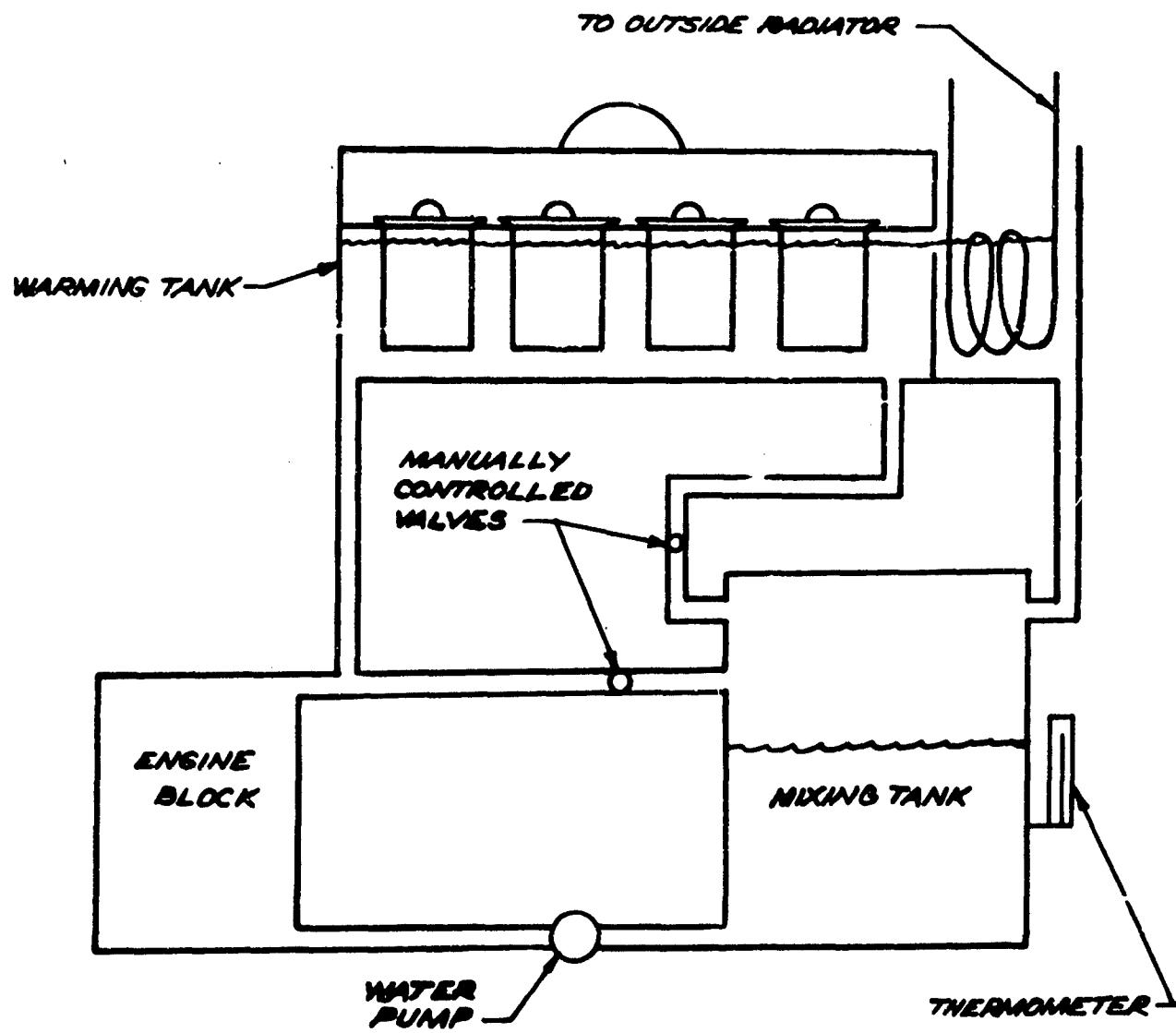
FIG. A22   LOW TEMPERATURE WARMING - INDIVIDUAL
SERVINGS

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should be such that there is a tight fit between the container and the warming tank to prevent water leakage. Also a large amount of liquid should flow past the container to increase heat transfer. Again the manual-bypass or thermostatically controlled valves prevent excessive engine cooling during initial startup of warming.

c. High-temperature, individual serving

Figure A23 is a method for the high temperature cooking of individual servings. This is accomplished by simply directing the hot ($1200^{\circ}F$) exhaust gases into gas-tight enclosure which is fitted with individual containers. These individual containers can be replaced by a grill for frying foods. The cooking area is hooded so that cooking odors can be vented to the outside. The hood is equipped with a device which allows it to be raised and lowered. The exhaust gas is simply vented to the outside after passing the cooking area. One disadvantage of this system is that there is no control over the heating. When the engine-generator set is running, the cooking area may become excessively hot.

d. High-temperature, large-batch serving

Figure A24 represents a method of using the exhaust waste heat of the engine-generator set for baking or some other type of high-temperature, large-quantity, food preparation. This method directs the hot exhaust gases around an oven, which is sealed so that exhaust gases can not get into the baking area. An alternate duct, equipped with a gas-tight box to prevent exhaust gas from leaking into the shelter contains a manually controlled damper, (A), which is used to control the oven temperature by controlling the flow of the hot gases. Damper B could be controlled by a bimetallic strip.

Damper A should be manually set to optimize the controlling function of damper B. Damper A should never be allowed to close completely; a mechanical stop or hole in the demper would be

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COVER

MUFFLER
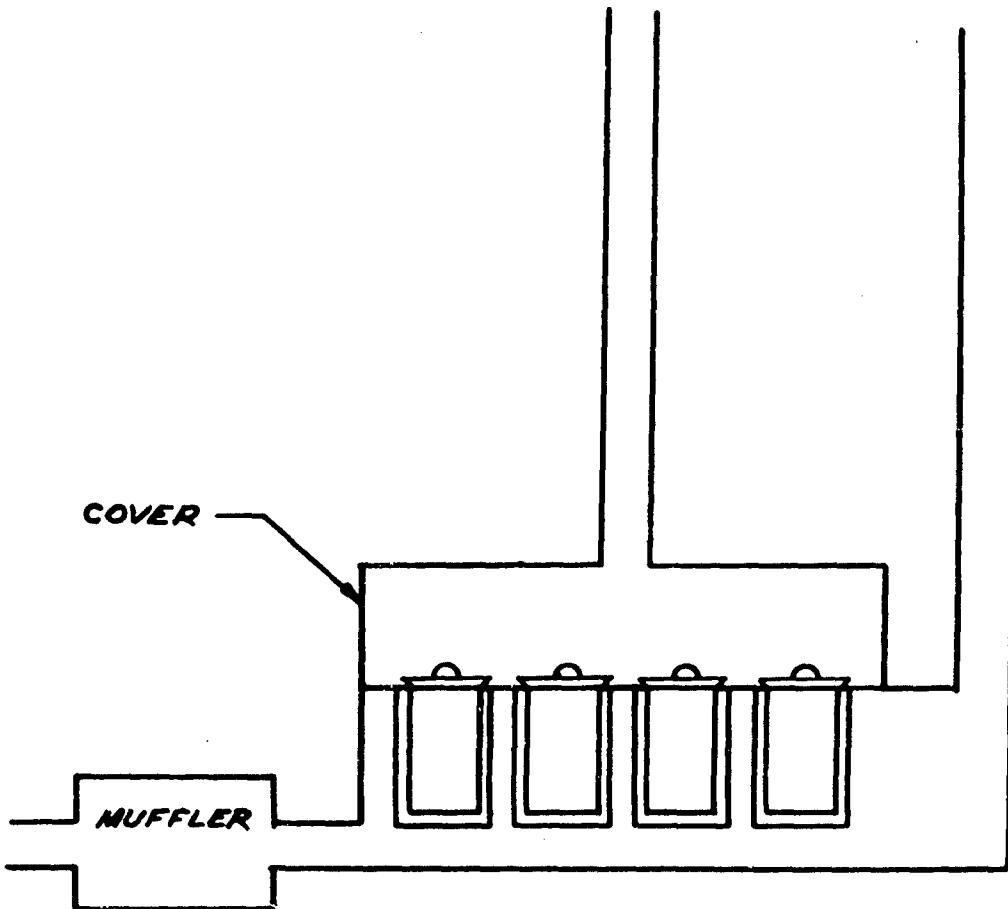
FIG. A 23 HIGH TEMPERATURE COOKING OR BAKING
(NO CONTROLS)

B-2711

DAMPER A

OVEN

MUFFLER

DAMPER B
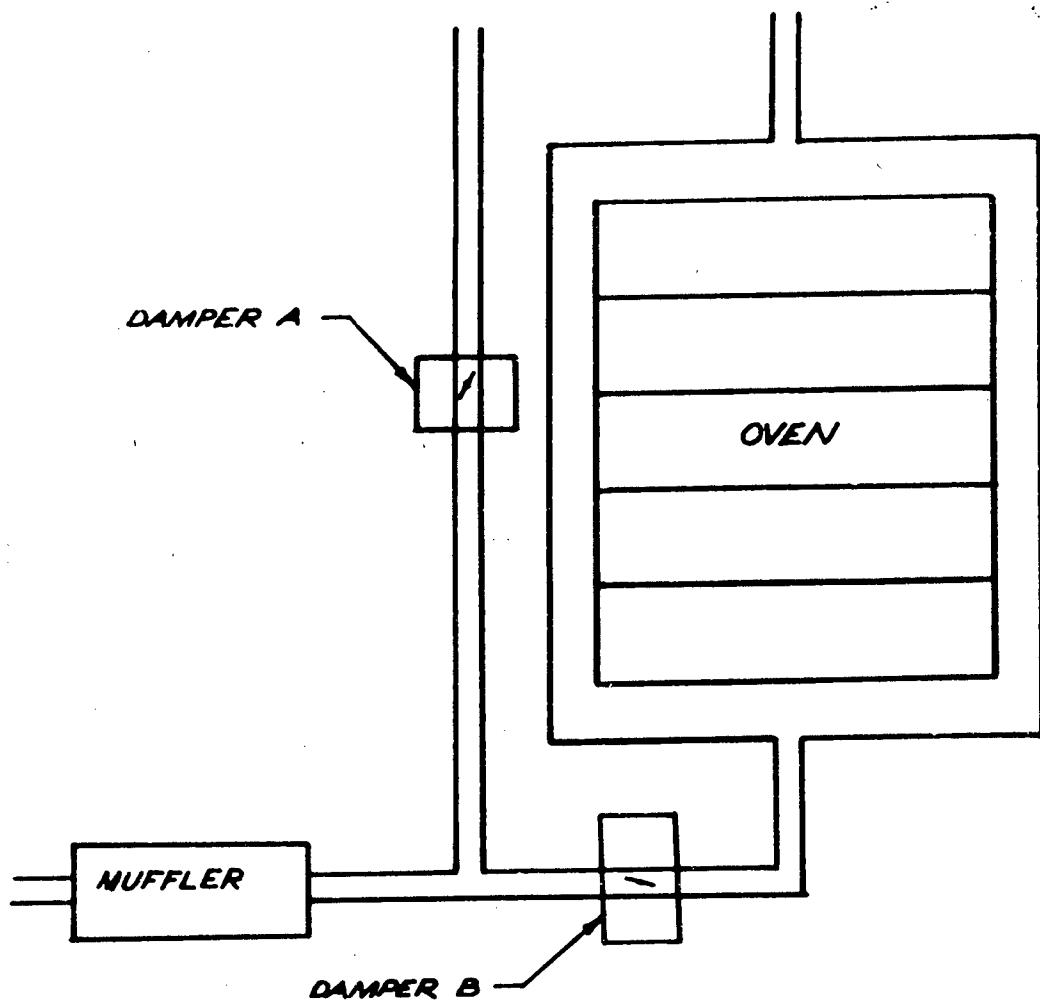
FIG. A 24 HIGH-TEMPERATURE COOKING OR BAKING
(WITH CONTROLS)

sufficient to prevent complete closing. Thus the
engine can always exhaust the products of
combustion.

5. Utilization of Waste Heat for Water Heating

Many of the schemes shown earlier (Figs. A11, A13
and A14) had hot water supplies as an integral part
of the cooling system. The engine coolant could
either be utilized directly for shelter activities or it
could be used to heat water in a heat exchanger. How-
ever, if air-cooled engines utilizing contaminated air
are to be used as a shelter power supply, the exhaust
gas would have to serve as a heat source for hot water.

a. Liquid-liquid heating

Figure A25 is similar to Fig. A13 except that
in Fig. A25 the heat removed by the heat ex-
changer coils is carried by water through another
heat exchanger before it is finally rejected to the
atmosphere. The intermediate heat exchanger
is located in a tank of water to be heated for
shelter use. Again the temperature of the water
in the mixing tank controls a pump, which keeps
the engine water inlet temperature constant.
The system is also equipped with the usual ex-
pansion tank and means for replenishing water
to the closed system.

b. Gas-liquid water heating

Figure A26 shows a method of utilizing hot engine
exhaust gases to heat water for shelter use.
A coil containing water is suspended in the
exhaust duct. As the water is heated it circulates
by free convection. The cooler exhaust gases
leave the shelter through the exhaust pipe. This
water heater construction is similar to the mono-
tube in the flash boiler shown later in Fig. C5. Of
course the hot exhaust gases could also heat water
in a tank by passing through tubes as in a fire tube
boiler. This method of heating a fluid is also
shown later in Fig. C5.

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EXPANSION TANK

TO OUTSIDE RADIATOR

HOT WATER

COLD WATER

DRAIN

PUMP

HOT →

ENGINE BLOCK

COOL ←
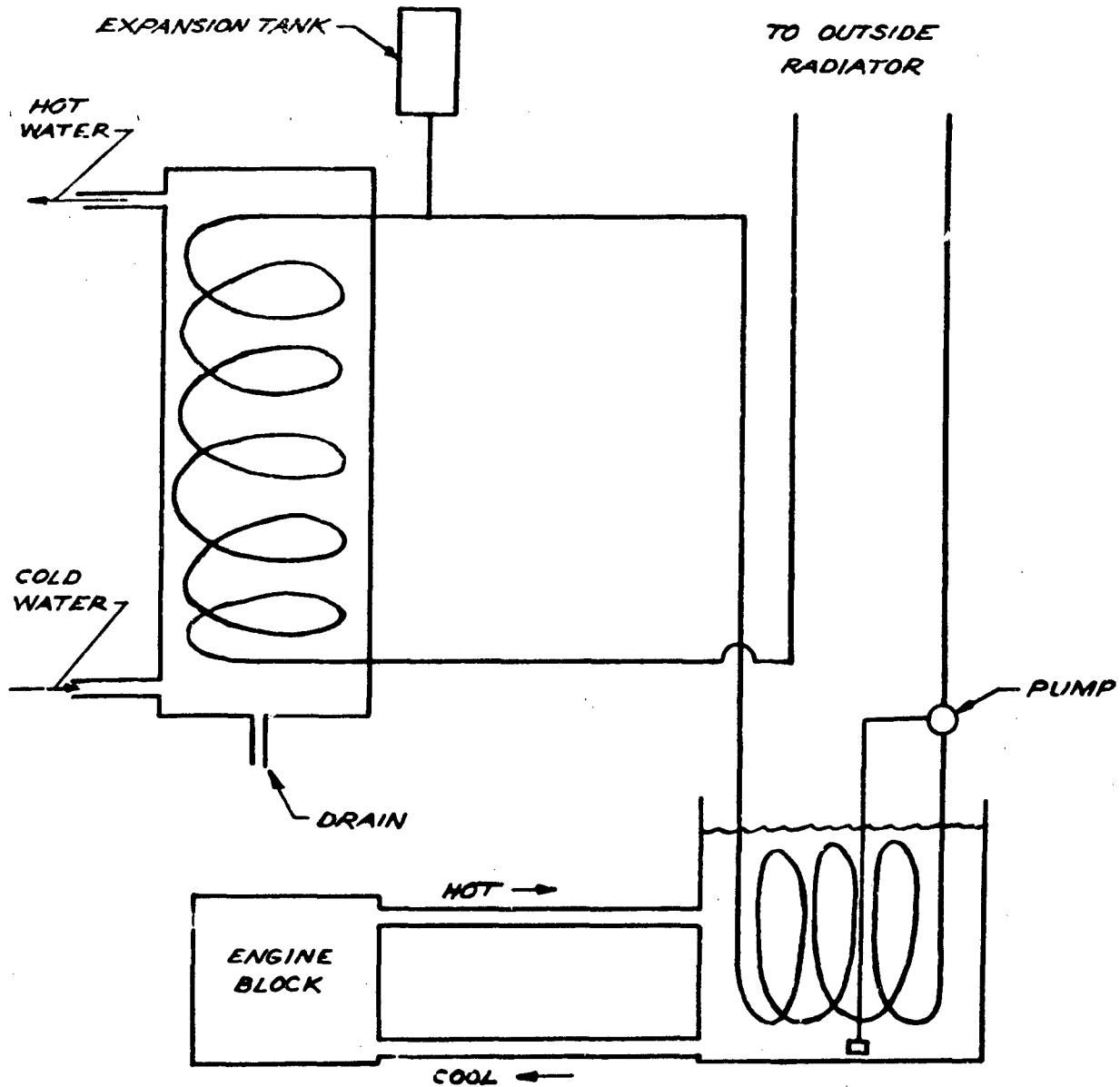
FIG. A 25   LIQUID - LIQUID WATER HEATING

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TO EXHAUST PIPE →

SAFETY VALVE

HOT WATER

WATER FROM SUPPLY →

HOT GASES FROM ENGINE →
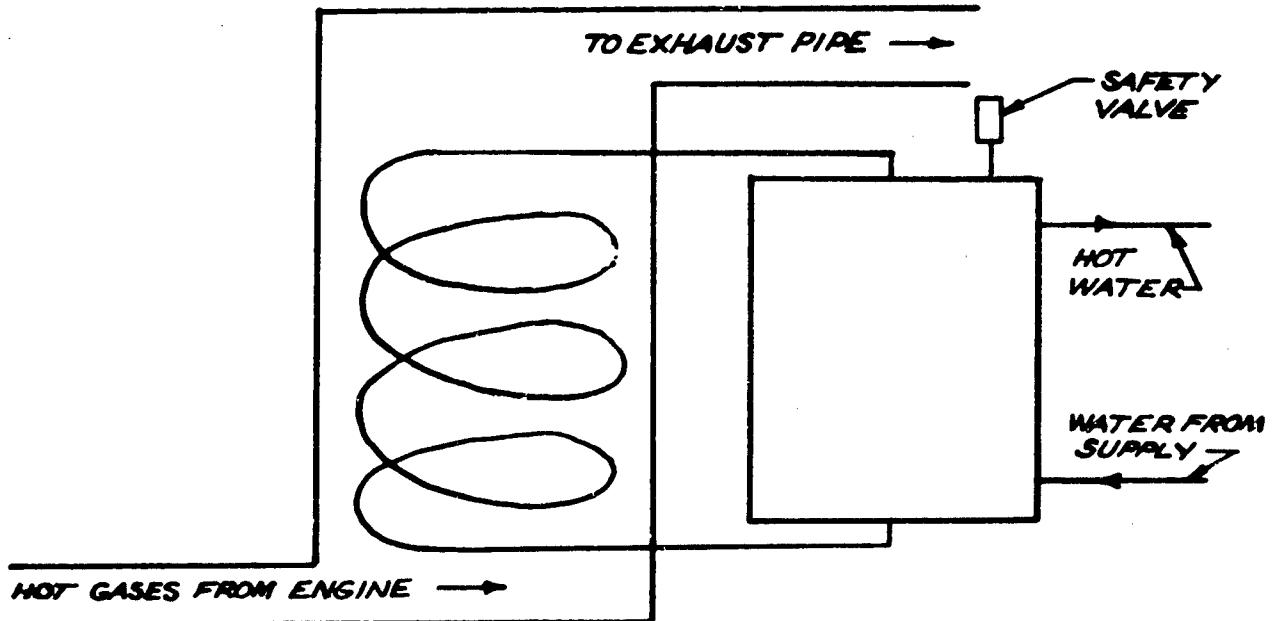
FIG. A 26   GAS-LIQUID WATER HEATING

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c. Steam generation

Figure A27 is a sketch showing a method by which steam
may be generated for shelter use. Hot exhaust gases are
passed over inclined finned tubes containing water. Some
of the water is evaporated and is stored as steam in the
steam chest above. The inclined leg is present to over-
come the back thrust created by the movement of the
steam as it is formed; the tube is insulated except in
the exhaust duct to prevent steam formation elsewhere.
The exhaust gases are vented to the outside in the usual
manner after some of the heat has been salvaged. Water
is fed into the system in a manner shown in Fig. A13.

The steam may be used for sterilizing utensils and
equipment, boiling clothes, and to operate an absorption
air conditioning system such as an NaOH unit which also
offers a possibility of carbon dioxide control in a shelter.

H. Utilization of Excess Shelter Air

It is anticipated that waste air from the shelter-air-condition-
ing process will be more than sufficient to supply the
combustion air for the engine-generator set as well as pro-
vide proper control of noxious gases. Therefore the remainder
of the waste air may be utilized 1) to perform evaporative
cooling of the engine, and 2) to provide combustion air for
auxiliary heat sources.

1. Evaporative Cooling Process

Figure A28 shows a method to utilize waste shelter air
in an evaporative cooling process for engine cooling
requirements. Hot water from the engine block is
pumped through a coil, which is immersed in a
container of water, and is then returned to the engine
block. A valve, which is controlled by the temperature
of the water in the engine block, controls the rate at
which shelter air bubbles through the water reservoir to
maintain the engine coolant temperature at approximately
160°F, since the cooling rate of the system increases
with air flow rate. An alternate procedure would be to
pump the engine coolant directly into the reservoir and
add makeup water to replace that which is evaporated.

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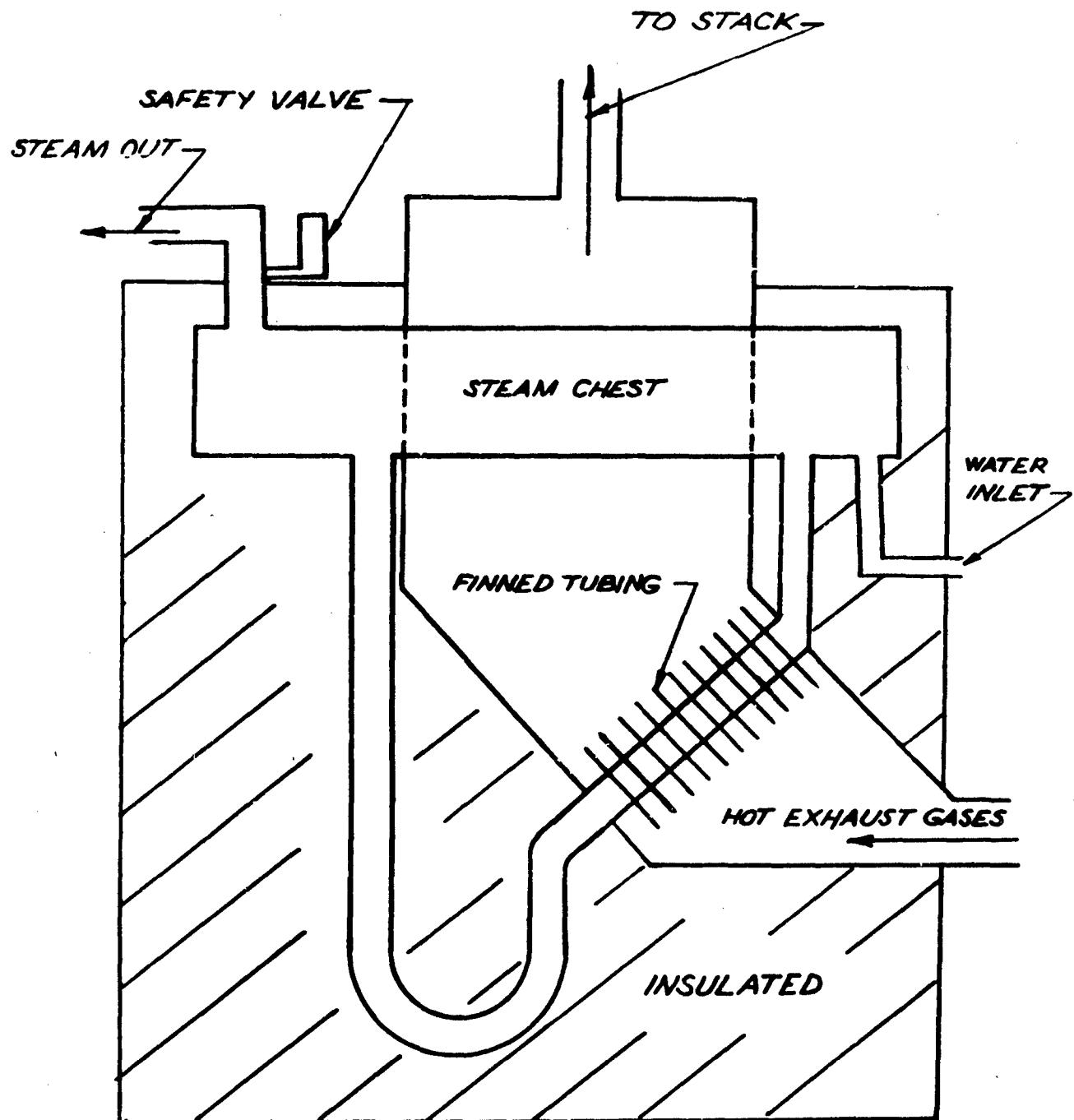
FIG. A27   SHELTER STEAM GENERATOR

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TO ATMOSPHERE

CONTROL VALVE

PRESSURIZED
EXCESS SHELTER
AIR

ENGINE
BLOCK

PUMP
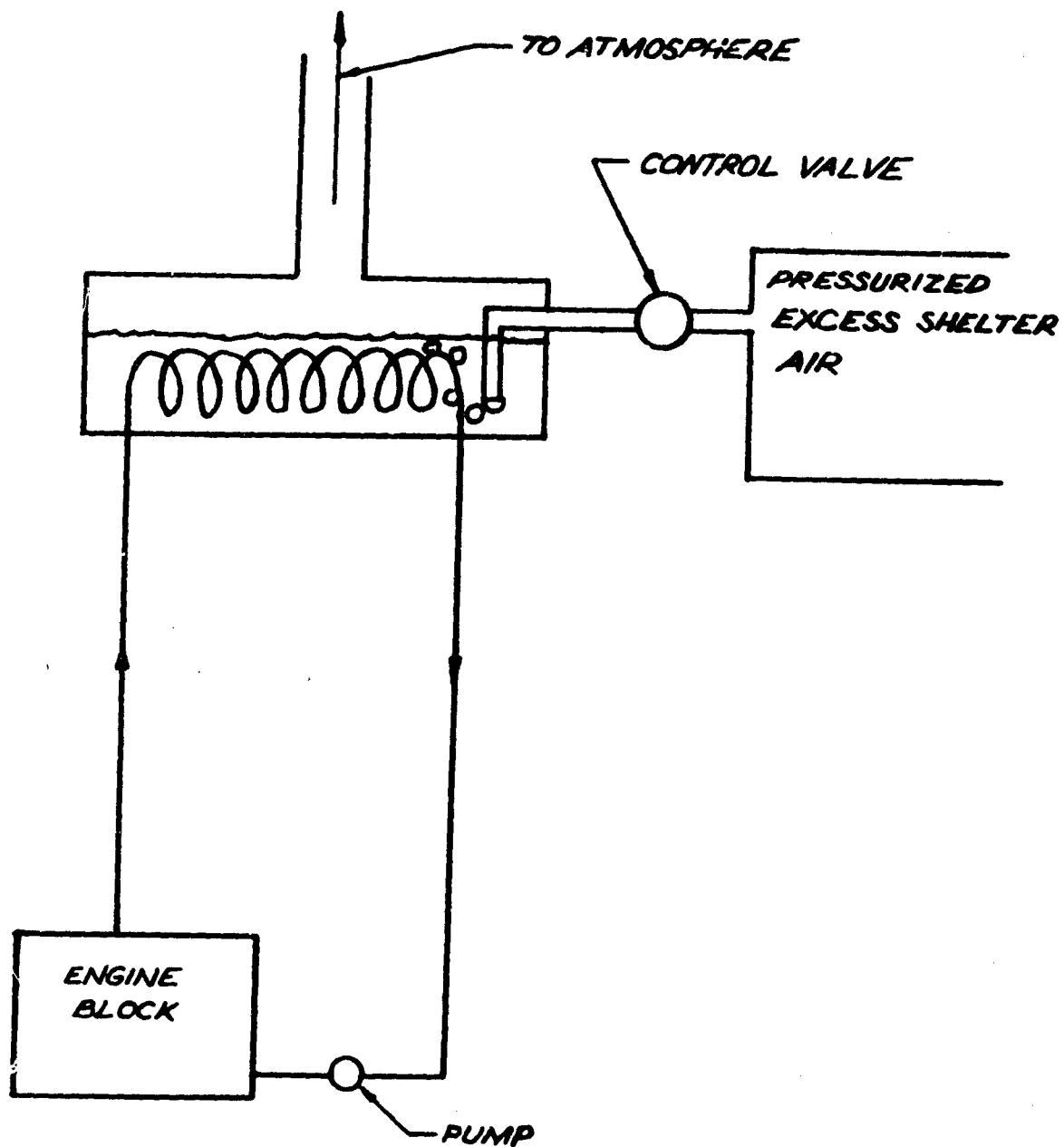
FIG. A 28 EVAPORATIVE COOLING EQUIPMENT

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The closed-system cooling system for the engine coolant in Fig. A28 would require the same charging arrangement shown in Fig. A13.

The advantage of the evaporative cooling process shown in Fig. A28 when compared to the method shown in Fig. A14 is that filtered air is used to promote rapid evaporation rather than sprays in contaminated air.

The advantage of the evaporative cooling system over the recirculated-water cooling system (Fig. A13) and over the well-water cooling system (Fig. A11) respectively is that the system in Fig. A28 does not require an external radiator and each pound of water lost removes approximately 1000 Btu (latent heat of vaporization).

The process by which heat is removed from the shelter is shown in Fig. A29 on a modified psychrometric chart. A typical ideal process would require shelter air at the conditions of point A. This air would be saturated and follow the saturation curve to point B where it would be discharged from the shelter. The amount of water lost per pound of air leaving the shelter in the process is the difference in the ordinates between point B and point A, while the heat removed per pound of exhaust shelter air is the difference in the values of the diagonal lines passing through point B and point A.

2.   Extensive Use of Filtered-Air Cooling

If an unlimited supply of filtered shelter air is available, an arrangement similar to Fig. A30 (but without the fans and external radiator) may be used. This system is based upon the requirement that the shelter air is exhausted at a pressure high enough above atmospheric to force the air over and around the engine-generator set with sufficient velocity to cool the unit. To cool a typical 5 KW engine-generator set requires approximately 700 CFM. This is enough air to maintain the CO_2 content of air at a safe level for 230 people (assuming 3 CFM/person) or to increase the allotment of air for 50 people to about 14 CFM per person. A 5 KW engine-generator

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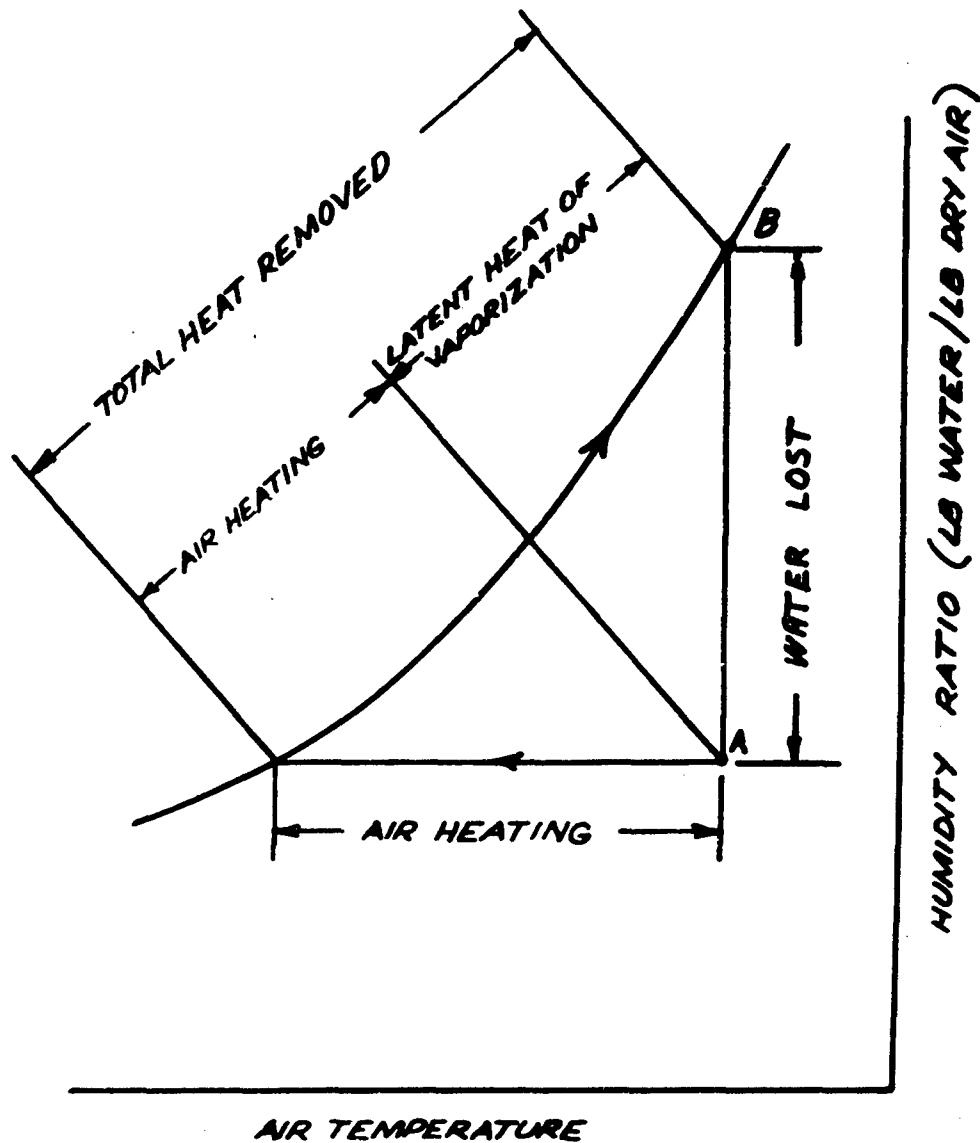
FIG. A29 EVAPORATIVE COOLING PROCESS

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AIR FLOW

EXPANSION TANK

MAKE UP WATER

PUMP

EXCESS SHELTER AIR

EXHAUST PIPE

WEIGHTED DAMPER
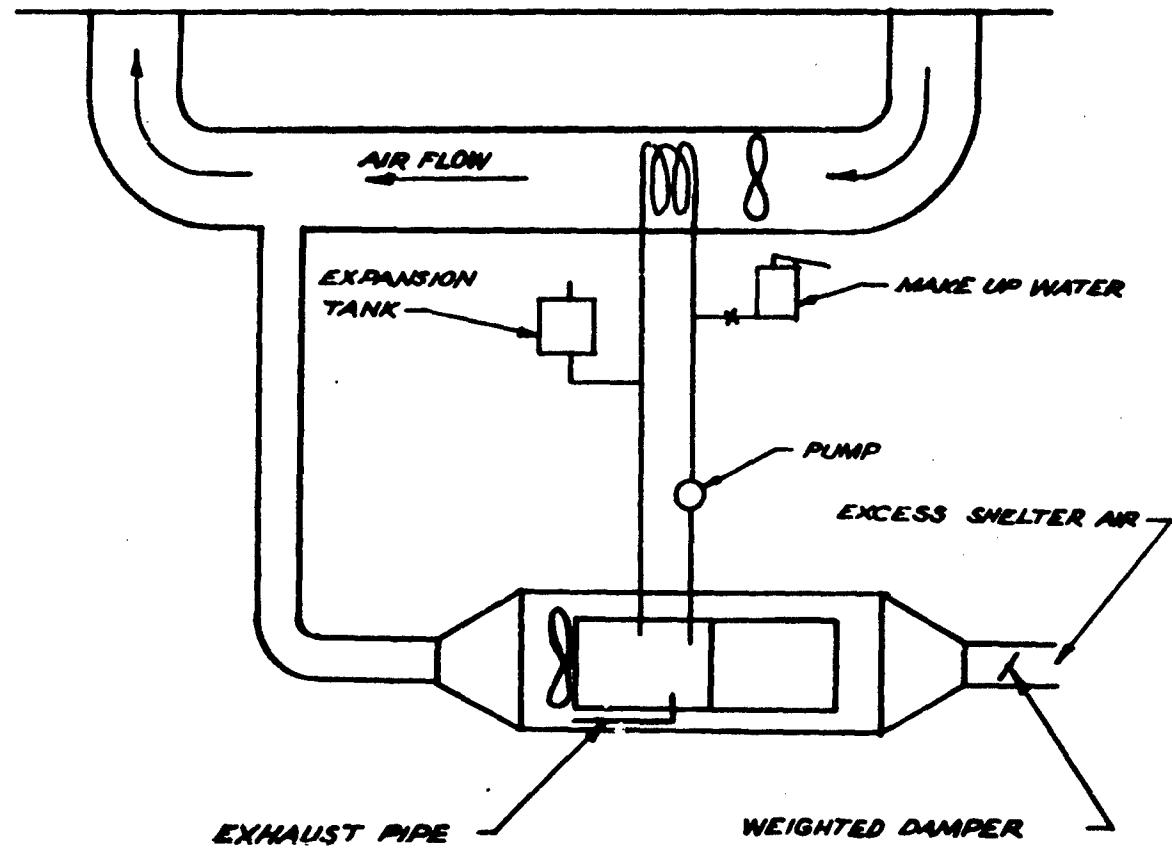
FIG. A30   FILTERED-AIR COOLING SYSTEM

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set supplying the needs of 50 people will provide 100
watts per person while the same engine-generator set
supplying the needs of 230 people will supply only 21
watts per person. Since it is anticipated that 21 watts
per person will not be sufficient power, the possibility
of supplying exhaust shelter air as a sole means of
cooling the engine-generator set will not be too likely.

A second solution to the problem of cooling the engine-
generator set with exhaust shelter air is suggested by the
failure of the first. If there is a limited supply of shelter
air available (say 150-200 CFM or an amount sufficient
to maintain safe CO_2 concentrations for 50 people) at a
pressure sufficiently higher than atmospheric to cause
air flow at an adequate velocity, this air can be used
to cool the generator and remove the heat transferred to
the air by radiation and convection from the engine.
The engine itself may be cooled by water and an external
radiator in the manner outlined in previous sections.

If approximately the same amount of air is available
as in the preceding method, but its pressure, and
consequently its velocity is too low for the proper
amount of heat to be transferred per unit time, a
method illustrated in Fig. A30 can be used.

3. Auxiliary Combustion Process

The question of whether or not excess shelter air
should be utilized for combustion processes such as
water heating, gas-fired absorption systems, and gas
lighting is a matter of economics. The following questions
must be asked:

a. Does the use of combustion processes reduce
the electrical load in the shelter and thus not
require generation of high-cost electrical
power only to have it do tasks suitable for
heat directly?

b. Is the cost of the fuel, burner, and other equipment
required to provide hot water or cooking energy
less than the cost of a heat exchanger system to
salvage heat from the engine when it is operating?

The first question may be answered quite readily. If the power-producer efficiency is 15 per cent and the combustion efficiency is 75 per cent, it would be five times more efficient to use heat directly rather than degrade the electrical power into heat. Of course, resistance heating is often more convenient than combustion.

The second question was answered tacitly during this study when a request for a 25,000 Btu/hr waste heat recovery unit was declared to be too small to be of interest to many manufacturers of heat exchangers. On the other hand, burners, water heaters, and small-size cooking equipment utilizing combustion processes are readily available (mass produced).

Figure A31 illustrates a means to use waste shelter air in a combustion process. A suitable burner, along with a throttle to control the rate of air flow and a manual valve and damper to equalize the shelter and burner pressure during ignition, is installed in the air exit duct. A manometer allows the operator to equalize shelter and burner-chamber pressures. Heat is removed by a water filled coil in the flame, while the exhaust gases pass out of the shelter through a vent.

I. Criteria for Equipment Selection, Installation, Maintenance, and Utilization

    1. Engine-Generator Equipment Selection

        a. Acceptance tests

        The conventional method of evaluating an engine by its hours of continuous operation before failure is not necessarily a reliable criteria for the approval of an engine for the shelter application since it is known that this application requires a considerable number of cold starts during the exercising period. This "cold" operation of the engine causes considerably greater wear rates than the operation of a "hot" engine (Fig. A9). Therefore, it is

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EXHAUST GASES

DAMPER

HEAT REMOVAL

MANOMETER

VALVE

THROTTLE

BURNER

AIR IN

FUEL

VALVE
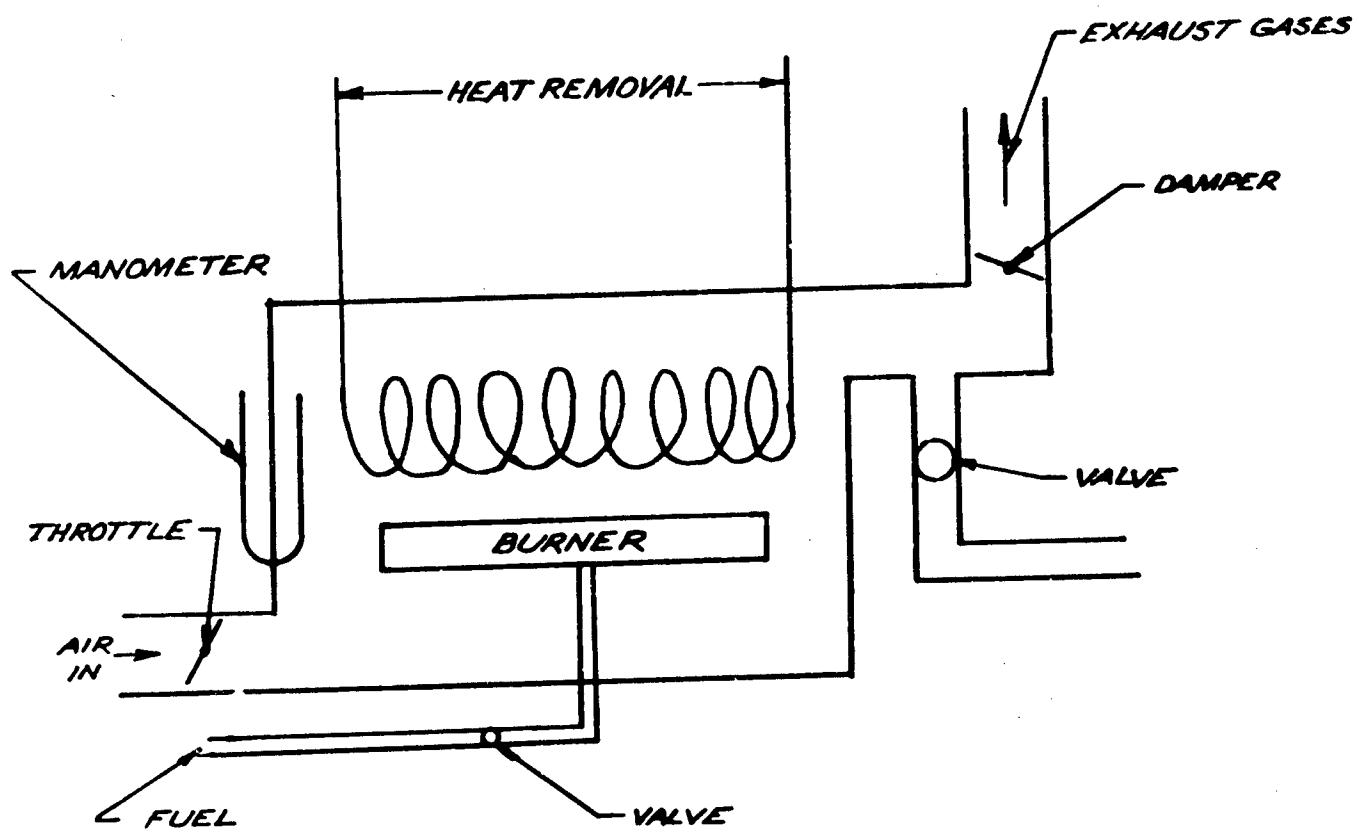
FIG. A31   BURNER FOR A SHELTER

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desirable to (1) develop a test procedure for evaluating engines for the shelter application and (2) determine if this test can be correlated with the available continuous-operation data.

It is realized that corrosion and wear are the two factors that would be most likely to cause failure of an engine-generator set. Therefore, it is desirable to evaluate the effects of these phenomena. The ten-year standby life requirement of the units makes actual field testing impractical. However, a realistic accelerated test appears to be possible. The factors influencing the tests and the accelerated test program are discussed below.

a-1. Corrosion

All external parts of the engine-generator set will store ten years if kept reasonably dry. This can be accomplished by heating the set with light bulbs and thereby causing it to be the warmest item in the vicinity. Condensation will occur at the coldest spot in the system and moisture on the set due to condensation during stand-by will be eliminated. Possible wetting of the engine by the entrance of liquid water into the engine room can be eliminated by proper design of the room and ventilation system. Also, the installation of sump pumps for usage in an emergency can be a further safeguard. The large number of ten-year-old engines and generators that are still functioning is evidence that keeping the outside of an engine-generator set stored under reasonably dry conditions will prevent failure due to corrosion of the external surfaces.

The internal surfaces of the engine on the engine-generator set will corrode if not protected by a layer of lubricating oil and made free of condensation. This lubricating

oil is subject to drainage from the oiled
surface; hence, if the surfaces are not
re-oiled with oil from the crank case, they
will corrode. However, field experience
by engine manufacturers shows that if the
engine-generator set is exercised once a
week for one half hour, this type of corrosion
(and also corrosion of the collector rings in
the generator) is not a problem. Since
weekly exercising is advised for the shelter
application, the corrosion of the interior of
the engine or the generator should not be a
serious problem. Consequently, an ac-
celerated corrosion life test of these
components is not essential.

a-2. Wear

The above discussion indicates that wear is
of greater importance for evaluation by an
accelerated life test. Reference A5 indicates
that most rapid wear occurs during the first
half hour of engine operation (Fig. A9). This
is definite evidence to support the fact that
engine-generator set manufacturers do not
expect maximum life from their engines when
weekly half-hour exercising periods are used
for a ten-year period. The reference cited
reports a very significant fact that the data
shown in Fig. A9 were reproducible whether
the engine had been shut down for several
hours or as long as several days. The only
requirement was that the shut-down period
be longer than two hours between runs.

This observation indicates that the wear
rate of an engine being exercised weekly
for a half-hour period may be duplicated
by a test program in which the engine is
cooled to expected shelter temperature,
exercised, and recooled to shelter tempera-
ture on a 6 to 12 hour cycle. Hence, ten-year
wear due to exercising could be duplicated in
a period of 130 days.

The absence of a suitable approval test for the shelter application suggests that a temporary test procedure require that the engines have at least 1,000 hours continuous operating life at full load. This more conservative test would eliminate the low cost economy engines from shelter application and allow acceptance of the heavy duty engines.

b.   Engine-generator set design

There is a considerable difference in design procedures among the various manufacturers of engines. Therefore, a detailed evaluation of specific designs was considered beyond the scope of this program. However, several design features appear sufficiently prominent that they should be mentioned.

b-1.   Valve faces and seats

The wear of valve faces and seats is the most probable source of engine failure. The use of stellite valve faces and seats is highly desirable for the shelter application because the engine would be useless with burned valves and repair would be very difficult.

b-2.   Bearings

Attempts to eliminate bearings for economical purposes, such as having a crankshaft supported directly on a die casting as a bearing surface, should be avoided unless there exists definite evidence that the omission of the conventional bearing (bushing, ball bearing. roller bearing, etc.) will not cause premature failure of the engine-generator set.

b-3.   Castings

Cast iron is preferred to die cast aluminum construction. If the cylinder block is die cast, it should have a cast iron sleeve for

the cylinder walls for better wear resist-
ance. Another disadvantage of aluminum
castings is the possibility of stripping threads
during emergency repairs; cast iron threads
are less often stripped.

b-4. Magneto

The points of the magneto may become pitted
or corroded and thereby cause improper
functioning of the engine or a complete fail-
ure. It would require less skill to replace
a magneto that can be removed from the set
as a unit than it would to replace the points
of a magneto that had the components per-
manently attached to the engine (such as
having the magneto housing an integral part
of the flywheel.

c. Instrumentation

The crucial nature of an engine failure indicates
that a certain amount of instrumentation is desir-
able in order to anticipate and prevent trouble.

c-1. Temperature gauge

Liquid-cooled engines should have tempera-
ture gauges in the liquid coolant outlet to
insure that excessive coolant temperatures
are detected. A temperature above $200^{\circ}F$
would indicate an unsatisfactory operating
condition.

If the engine is air cooled, the temperature
gauge should be located in the air stream
immediately before the engine-generator
set. The upper temperature limit of the
cooling air entering for safe operation would
be $120^{\circ}F$.

For engines cooled by well water or other
continuous water supplies, the inlet water
temperature to the engine should be checked.

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The inlet water temperature should rise to at least 140°F in less than one half hour after starting of the engine and should not fall below this temperature during engine operation.

c-2. Oil pressure and oil level guage

If the engine has an oil-pump system, an oil-pressure gauge should be available to determine if the oil pump is functioning satisfactorily.

The engine should be equipped with an oil-level gauge. Provision should be made to add oil while the engine is running.

c-3. Intake manifold pressure gauge

Unusual circumstances for operating the engine might result in overloading the engine and subsequent premature failure. A pressure guage on the intake manifold would indicate this situation. The manifold should always be at a partial vacuum for continuous full-load operation. The application of engine load might momentarily cause this vacuum to be reduced.

d. Instruction manual

The engine-generator set should be supplied with the manufacturer's instruction manual with 1) instructions for starting the set, 2) procedures for detecting engine or generator troubles, and 3) repair procedures. These manuals would be different for the various manufacturer's engines, but they should contain sufficient detail that a reasonably intelligent person could handle minor repairs. The instructions should include the following information in detail:

d-1. Starting

(a) Precautions before starting (oil level check, etc.)

(b) Starting procedure

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(c) Carburetor adjustment

(d) Throttle adjustment

d-2. Detection of troubles

(a) Ignition system malfunctions

(1) Defective spark plug

(2) Defective magneto

(3) Defective wiring

(b) Fuel system malfunctions

(1) Gas supply to fuel pump

(2) Gas supply to carburetor

(3) Flooding

(4) Insufficient fuel

(5) Idle-adjustment

(6) Rich-lean mixture adjustment

(7) Plugged or restricted exhaust manifold

(c) Repair and maintenance procedures

(1) Cleaning, re-gapping and replacing spark plugs

(2) Replacing magneto

(3) Replacing distributor points

(4) Changing oil

(5) Replacing oil filter

(6) Cleaning air filter

(7) Cleaning carburetor

(8) Replacing gaskets damaged during repairs

(9) Lubricating the engine

(10) Cleaning generator collector rings and replacing generator brushes and brush springs (if feasible).

(11) Replacing defective swi .hes at main power distribution station.

These instructions should be detailed. For example, starting the engine by a rope starter should include an instruction such as: "manually take the engine off the compression stroke before pulling the rope". This is indicated by the ease with which the rope can be pulled. The instructions should be explicit. If a blue wire is used in the set, the instructions should refer to the blue wire instead of just the wire. Written instructions should be supplemented by diagrams to both insure that the engine repair man knows what to do and to allow him to "double check" himself so that he is more certain that what he has done is correct. This is important in that if the difficulty is hard to detect or correct, he can be sure that portions of his completed work are satisfactory. He will not then waste time in duplicating past efforts because of indecision.

The instruction manual should include a tool and material list for accomplishing the above mentioned procedures for detecting, cleaning, and repairing.

2. Auxiliary Equipment Selection

   a. Exercising equipment

   a-1. Manual operation

   The only equipment required for manual exercising during the stand-by period is a clock (or watch) and a pencil and notebook to record the length of the exercise period and the date. This essential record of cumulative running time could be used to assure oil changes after 26 hours of operation.

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Also detailed instructions of the exercising
procedure would insure proper attention by
various service personnel.

An air purge fan used to ventilate the shelter
engine room and the engine air filter and fuel
filter should be cleaned at least yearly; the
cleaning date should be recorded. In general,
a log indicating exercising history should be
maintained.

a-2. Automatic operation

Various degrees of automation could be used
during the exercising period. The engine-
generator set could be automatically started
and stopped at the desired times with available
equipment. This equipment should be (and
generally is) equipped with a safety circuit so
that if the engine does not start in a reason-
able number of attempts the starting procedure
will not be repeated and cause damage. The
engine-generator set should also be equipped
with a temperature-controlled safety device
to prevent overheating the engine. The cooling
system will be novel for the shelter applica-
tion, and consequently precautions should be
taken until reliability is proven by field experi-
ence. If the engine has a pressurized oil system,
the automatic exercising system should have an
oil-pressure safety device to prevent the opera-
tion of the engine with low oil pressure.

The installation of automatic exercising equip-
ment does not entirely eliminate attention by
personnel. Oil changes, filter cleaning,
servicing, and checking of the generator are
still required.

3. Application of Load

a. Electrical load

The starting load for electric motors is higher than
the normal operating load. In order to load the
generator to its maximum capacity, the inductive

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loads (motors) should be applied first. Therefore, a sequence for applying the various electrical loads is required. This method of load application can be accomplished by a series of hand switches. The time internal between the closing of the switches could be short (one second) as this peak transient load is of very short duration. However, the order in which the loads are applied is important. The largest motors should be started first, the smaller motors next, and finally lights and pure resistive loads should be applied.

Equipment for automatic sequencing of the starting loads can be purchased (A8). If this arrangement is used, provision should be available (generally part of this equipment) to eliminate the least crucial part of the load in case of severe overloading.

b. Mechanical load

The possibility of having part of the load such as blowers driven directly by the engine instead of using electrical power from the engine-generator set should be considered. This could be accomplished by a belt-driven arrangement. The idler pulley could be used to act as the clutch. However, clutches are available for such an installation. The mechanical load would be started last in the load application sequence as it would have the starting characteristics of a resistive electrical load due to the ability of the clutch to gradually apply the load.

The use of a mechanical drive would result in (1) the elimination of a motor, (2) a smaller-size generator requirement, and (3) more efficient utilization of the fuel supply because the generator is only 70 per cent efficient.

4. Shelter-Power Manual

The engine-generator set manual was concerned with the operation and servicing of the engine-generator set. A similar manual should be prepared by the shelter-power-system designer. It would contain, among other data deemed pertinent by the designer,

instructions for operation, inspection, maintenance, and
emergency procedures concerning the fuel supply, cool-
ing system, exhaust system, and electrical system that
were not part of the engine-generator set. The load-
application sequence for starting the engine-generator
set would also be included in this manual. A recom-
mended procedure for reducing the load, if necessary,
should also be included; this should contain descriptions
of results to be expected for certain shelter activities in
case of power failure in order to facilitate decisions that
would have to be made at the time. For example, it
may become evident that longer occupancy would be re-
quired; hence, fuel must be conserved.

5. Engine-Generator Set Installation

   a. Procedure

      The engine-generator set should be installed as
      recommended by the manufacturer. The most
      satisfactory methods for fuel storage, waste heat
      recovery systems, and cooling systems should be
      utilized. Several suggested methods were pre-
      sented earlier in this study. The first test run
      should be made according to instructions. If the
      engine had not had a break-in period at the factory,
      the manufacturer's break-in instructions should be
      followed. If not specified, the break-in oil should
      be a S.A.E. 30, non-detergent oil to prevent glazing
      of the cylinders. The purpose of the break-in period
      is to allow the newly-machined engine surfaces to
      "wear in" to give optimum engine performance,
      with respect to minimum oil consumption, maximum
      life expectancy, and maximum efficiency.

   b. Inspection:

      The following precautions should be taken regularly
      during the stand-by period:

      b-1. Check the oil level in engine and add oil
           if level is low.

      b-2. Drain water from the water trap in the
           exhaust line.

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b-3. Check the fuel gauge for excessively fast consumption of fuel. This would indicate improper operation or a leak in the fuel line.

b-4. Check the fuel line and joints for leaks. Major leaks will be indicated by liquid spots on the floor.

b-5. Check the water level in a liquid-cooled system and add a rust inhibitor once a year.

b-6. Check the water system for leaks.

b-7. If the engine has a fan belt, check the side that contacts pulleys.

b-8. Check the equipment for loose bolts due to vibration

b-9. Follow the designer's recommendations for belt tension. A belt that squeaks during constant load operation is probably too loose and will glaze and wear fast due to slippage. More tension on the belt is required. Excessive tension causes excessive loads and wear on shaft bearings.

b-10. Check the wiring for cracks in insulation, particularly high voltage wiring from the coil to the spark plugs.

b-11. If the system has rubber hoses or tubes, check for bulges and soft spots. Replace hoses or tubes if these are detected.

b-12. Check the water level and hydrometer reading of batteries.

6. Engine-Generator Set Maintenance

a. Preventive maintenance

Engine-generator sets require surprisingly little preventive maintenance. The following precautions would be sufficient for a preventive maintenance program:

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a-1.   Clean and re-gap the spark plugs annually.

a-2.   If engine has a distributor, check the points annually and replace if they are pitted.

a-3.   Change the oil and lubricate the engine according to manufacturer's recommendations.

a-4.   Clean the oil filter and air filters according to manufacturer's recommendations.

a-5.   Clean oil and dirt from the ignition system wiring annually.

a-6.   Replace the starter rope if it becomes worn.

a-7.   Adjust the carburetor (only if necessary) according to the manufacturer's instruction manual.

b.   Emergency repairs

The following spare parts are recommended for the engine-generator set:

b-1.   Gasoline engine

   (a)   spark plugs

   (b)   distributor points

   (c)   fan belt

   (d)   magneto

   (e)   generator brushes and springs

   (f)   air filter

   (g)   fuel filter

   (h)   carburetor

   (i)   gasket overhaul set and gasket compound

   (j)   can of cleaning fluid

b-2.   Diesel engine

   (a)   fuel injector

   (b)   pertinent items above

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The purpose of the gasket overhaul kit is to allow an elaborate overhaul in the event that it is necessary, and that qualified personnel happen to be available. It is not exceedingly difficult to overhaul small engines. The cleaning fluid would be for cleaning the parts (particularly gums from the carburetor.

c. Lubrication

In addition to the oil changes, the equipment may be equipped with oil wells and/or grease fittings. These should be lubricated according to the manufacturer's instruction. The oil should be stored in one-quart sealed containers and the grease in conventional metal containers. These containers should be stored in a reasonably dry place so that they will not corrode.

7. Mode of Operation

After the engine-generator set has been installed, procedures for operation both during the stand-by period and the time of actual usage are required. These procedures are described below.

a. Stand-by period

a-1. Purge the engine room with fresh air to eliminate the danger of a combustible mixture. The procedure would be to start an air purge fan or blower (operated by commercial power) and operate it for a time (determined by the size of the area to be purged).

a-2. After the air purge was completed, the engine would be started.

a-3. Soon after starting, the sequential application of load would be executed. Among the items to be started would necessarily be the cooling system. This would not have to be the first item started, but the entire sequential starting program should be completed within 2-3 minutes after the engine started. If diesel fuel or gasoline is being used, the load should be 90 per cent of the rated engine load. If LP gas is the

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fuel, the load should be 50 per cent of the
rated engine load. These figures are
selected to prevent carbon build-up in the
engine.

The large electric motors should be started
first. Initial transient currents 500 per cent
of rating may be expected (A9). If this is
more than 110 per cent of the generator
rating, low voltage motor starting boxes
should be used. The mechanical load should
be applied last if the load is driven through
a clutch.

a-4. If personnel are on hand (equipment not on
automatic cycle), a check should be made to
determine if equipment operation is consistent
with the manual and the proper corrections
made.

a-5. The engine-generator set should be operated
for one half hour.

a-6. When removing the load from the engine-
generator set, the reverse procedure from
sequential starting would be satisfactory.

a-7. The engine should be stopped.

b. Emergency period

The starting procedure would be the same as during
the stand-by period. However, if the commercial
power for the air purge fan was not available, this
step would have to be omitted.

If power is not required at certain times, the
question arises whether or not to shut down the
engine-generator set. If the anticipated time is
less than 30 minutes, the engine should be allowed
to function on the regular cycle. If the time is
greater than 30 minutes, the engine-generator set
should be shut down. These recommendations are

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made so that (1) a hot engine is not started and stopped unnecessarily, (2) undue adjustment of speed is not made, and (3) fuel may be conserved.

8. Comparison of Competitive IC Engines

If a standard acceptance test has been adopted and several manufacturer's engines are available and satisfactory, a decision has to be made as to which one should be selected. The factors to be considered are:

a. Cost

b. Service by the manufacturer's representative after installation during the stand-by period

c. Life expectancy

d. Ease of starting

e. Simplicity of maintenance

f. Simplicity of inspection

Since the acceptance test will require experimental data concerning the effects of a large number of cold starts on engine life expectancy, it is impossible to quantitatively evaluate these properties, but the following aspects of the evaluation should be considered.

a. During the 1-year stand-by period much data on the engine-generator set will be accumulated. Periodic inspection by trained personnel will make these data much more useful than observations made by untrained personnel.

b. If the life expectancy of the engine-generator sets is considerably longer than the acceptance test requirements, this factor loses significance.

c. All the sets should start relatively easily. However, if any particular one has more starting difficulties than the rest, it should be eliminated from future application.

d. Undue maintenance problems or difficulty in inspection (such as checking the oil level in a hot engine) should be important as well as purchase price.

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J.   Physical Arrangement of the Shelter System

1.   Engine Generator Set Location in the Overall Shelter air Stream

The air passing over the engine will contain obnoxious oil fumes and the air discharging from the cylinders during the combustion process will contain noxious carbon monoxide and other products of combustion. Therefore, once the air has passed over or through the engine it should be isolated from the "breathing" air used in the shelter even though it may still be used for a heat exchange or a combustion process.

Therefore, the engine-generator set (if it uses shelter air) should be located near the waste-air exit of the shelter. If there are no heat exchange processes to scavenge waste engine-generator heat or combustion processes that utilize the excess air from the set, the engine-generator set should be located next to an air exit in the shelter. If heat exchange or combustion processes are used, these processes should be the only items in the air flow stream between the engine-generator set and the air exit of the shelter.

2.   Fuel Location in the Overall Shelter Air Stream

The fuel supply should be isolated from the shelter and arrangements should be made to continuously purge these areas having any fuel storage with a small stream of air to prevent gases from the fuels from reaching sufficient concentration to cause an explosion. The fuel storage area should not normally be occupied by people or oxygen consuming equipment; therefore, the quantity of purge air required would not be large. The exact quantity of purge air required would be determined by the capacity of the fuel storage facility and the degree that the facility was properly used.

The most fool-proof procedure would be to use as much purge air as possible and vent the purge air to the outside through an explosion-barrier screen (similar to those on mine lanterns). This precaution would reduce fuel vapor concentration and only permit explosions outside of the shelter provided that suitable precautions against explosion in the fuel storage area are taken (elimination of sparks and heat).

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3. Location of the Engine-Generator Set and Power Loads

a. Electrical Power Distribution

The location of the engine-generator set relative to the electrical loads is not critical because electrical energy is easy to distribute. The distribution system should consider such factors as heat or moisture, decomposition of insulation, adequate size wiring, and proper fusing to minimize the effects of local short circuits.

b. Mechanical Power Distribution

If a fan is a large power load, the inefficiency of the generator could be eliminated by using engine shaft work directly by means of a mechanical linkage (probably belts). A clutch would be required for large loads. One engine could drive both an electric-power generator and a mechanical load. The mechanical power transmission would be simplified if the mechanically driven device was located near the engine.

c. Hydraulic and Pneumatic Power Distribution

These systems would have flexibility in location with respect to the power producer. A major difference between these systems and the electric system is that usually power distribution fails if the electric wire breaks. This is generally not the case with hydraulic or pneumatic systems; however, these systems might need recharging before being put back into service. An inexperienced person, with a minimum of instruction, probably would repair an electrical distribution line easier than he could repair a hydraulic or pneumatic system.

4. Waste Heat Loads

The transmission of sensible heat always involves a heat loss. This can be minimized by short lines that are insulated. Location of the heat transmission lines so that energy lost in transit does not flow back into the shelter area should be studied for each individual situation.

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5. Space Requirements

The engine-generator set enclosure should have at
least six inches clearance between the set and the
enclosure wells. As a general rule, which may pos-
sibly be violated occasionally, the four sides of the
enclosure should be removable for engine repairs. A
minimum distance of 2 feet from the engine to the
nearest permanent wall is good practice.

If the engine-generator set selection has not been made
and the designer wishes to use a rectangular block for
representing the engine-generator set and the service
area for layout purposes, a 6 foot wide by 4. 6 foot high
by 8. 5 foot long rectangular parallelepiped would be
recommended for an enclosed 5 KW set. These dimen-
sions include the 2 feet clearance on all sides.

VII.   AC GENERATOR SELECTION

A.   Introduction

Considering that an exercising procedure is required for the engine during normal stand-by duty, it is not anticipated that the generator will become demagnetized nor be subject to failure.   Therefore, the discussion that follows is limited to description of the various units rather than details on maintenance and repairs.   Reference B1 contains most of the source material.

In subsequent discussion, the notation refers to the field as that winding which, when excited by a dc power source, produces a magnetic field.   The armature winding is that winding which, due to relative motion between the armature and magnetic field, develops an induced voltage to power an external electrical load.   Either the armature or the field may be rotated.

B.   Types of Rotary AC Generators

The generation of emf in an armature conductor depends only upon the relative motion between a conductor and magnetic field.   Therefore, either the armature conductor (which delivers electrical power to external loads) or the magnetic field may be mechanically rotated.

1.   Rotating - Field Type

   a.   Description

   The rotating salient-pole may be excited by either of two types of dc voltage sources.   Electrical power is delivered to the load by the stationary armature winding.

   a-1.   An external dc source is connected to the rotating field through slip rings and brushes.

   a-2.   A brushless shaft-mounted ac exciter on the same shaft as the main field provides dc using silicon diode rectifiers which rotate with the field and exciter.

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b. Application

The rotating-field generator is used for high voltage, high amperage, high speed applications because of the elimination of brushes in the load circuit, and ease of applying high voltage insulation. It is generally not available in a 5 kva or lower power rating because of cost considerations. There are also constructional difficulties (insufficient space on the smaller rotors for the salient-pole construction).

c. Electrical Characteristics of Rotating Field Generators

c-1. Terminal Voltage and Phase

Commercial rotating field generators above 7-1/2 KVA are available in the following choice of voltage and phase

Phase	No. Wires	Rated Terminal Voltage
1	2	115V
1	3	120/240
3	3	240
3	4	120/208

c-2. Voltage regulation is equal to $\pm$ 5% of rated voltage from no load to full load with automatic voltage regulator.

c-3. Frequency regulator is dependent upon the speed regulation of the prime mover. Commercial engine-generator sets obtain $\pm$ 1-1/2% using flyball governor throttle control. A combined frequency and voltage regulation of less than $\pm$ 10% is obtainable.

c-4. Speed

Generator speed is determined by the number of poles and desired frequency as follows:

Generator No. of Poles	Frequency	Prime Mover Speed
2	60 cps	3600 rpm
4	"	1800 rpm
6	"	1200 rpm
8	"	900 rpm
12	"	600 rpm

Generally, only 2-pole and 4-pole machines are available commercially in engine-generator sets.

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c-5. **Exciters and Field Control Methods**

DC and rectified AC exciters are usually mounted on the generator shaft. The field control is generally of the rheostat type for use with a saturated field. Automatic voltage regulators are generally available above 5 kva.

c-6. **Insulation and Temperature Rise**

Insulation of most commercial engine-generator sets is NEMA MG1-6.08 specification Class A with a 40°C temperature rise (Reference B3). The 40°C specification is based upon a 2 hour test at rated load conditions; a 50°C specification is based upon continuous duty at rated load conditions. Higher temperature insulation (Class B or H) is available as an extra-cost option if desired.

At least one of the commercial engine-generator sets operates with a 60°C temperature rise. Underwriters Laboratory Inc. (UL) temperature standards for electric motors reports an increase in rate of insulation deterioration and a deterioration of bearing lubricant when Class A insulated motor temperature rise is excessive. UL temperature rise limits for fractional horsepower motors (class A insulation) are 75°C for an open motor and 80°C for a totally enclosed motor.

c-7. **Short Circuit and Overload Capacity**

Commercial engine-generator set literature (B1) does not generally specify overload or short circuit capacity. One leading manufacturer claims his generator will withstand a 10% overload for 2 hours. Others do not specify.

c-8. **Enclosures**

Available enclosures include the drip-proof, splash-proof and totally enclosed.

c-9. **Efficiency**

This is defined as the ratio of electrical power output at the generator terminals to the combined mechanical shaft energy input and field excitation

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energy if externally excited. Efficiency varies from 70 to 85% depending upon the size of the generator (above 7-1/2 KVA).

2. Rotating - Armature Type

    a. Description

    Electrical power is delivered to the load through slip rings and brushes by the rotating armature conductors. The stationary field poles may be excited by either of two types of dc voltage sources.

    a-1. External dc source may be directly connected to the stationary field.

    a-2. DC or rectified ac shaft - mounted exciter may be mounted on the same shaft as the armature. Excitation voltage is provided by brushes and split rings respectively.

    b. Application

    The rotating armature generator is used for low voltage, medium amperage, medium speed applications in the 7-1/2 KVA and lower power range because of its inherently lower cost. As a result, almost all of the commercially available engine-generator sets in the 5 kva and down power range are of the rotating armature construction.

    c. Electrical Characteristics of Rotating Armature Generators

    Electrical characteristics of the generator in the 7-1/2 KVA and below range are almost identical to the rotating field type.

    The efficiency in the 5 kva and smaller sizes is between 65% and 75%.

3. Inductor Type

    a. Description

    A stationary field and stationary armature are utilized. The rotor is used to complete the magnetic path linking field and armature. Varying the air gap or magnetic

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reluctance as the rotor is rotated, changes the flux linking the armature and field induces an alternating voltage in the armature. DC excitation from an exciter regulator or other dc supply is required by the field.

b. Application

The inductor generator type is used for specialized applications where higher frequency is desired or poor sine waveshape can be tolerated. Small air gaps and critical alignment problems limit this generator from 2 kva to 15 kva applications. No commercially available 60 cycle generator of this type could be located, but a 400 cycle unit was found that indicated the electrical characteristics.

c. Electrical Characteristics of Inductor Type Generators

Since this machine is used primarily for high frequency generation above 960 cps for induction heating, 60 cycle units are not commercially available that have desirable electrical characteristics for the application.

4. Induction Type

a. Description

An induction AC motor driven mechanically above synchronous speed becomes a generator. Output frequency depends upon the rotor speed in relation to the frequency applied to the field.

b. Application

The induction generator is limited to electrical loads requiring a leading current. Principal application of this type is for frequency and phase conversions. It is unsuitable for inductive loads such as AC motors unless power factor corrected for a leading current with large capacitors. It is not suitable for emergency power applications because of the AC exciter power requirement.

c. Electrical Characteristics of Induction Type Generators

Since the induction generator can supply only leading current and must be excited by a 60 cycle voltage source, it has undesirable electrical characteristics for commercial loads which usually require a lagging current (electric motors).

5.   Permanent Magnet Type (B2)

   a.   Description

   This type is similar in principle to the rotating salient-
   pole field with the exception that the copper wire and
   laminated soft iron salient-poles are replaced by
   permanent magnet salient poles cast into an aluminum
   rotor assembly. No field excitation is required,
   thereby eliminating brushes and slip rings. The
   armature winding is stationary.

   b.   Application

   The permanent magnet generator is commercially avail-
   able for 60 cycle and higher frequency applications that
   can accommodate the voltage regulation range and
   degree of wave form distortion inherent with this type
   of generator.

   c.   Electrical Characteristics of Permanent Magnet
        Type Generator

   Electrical characteristics of the permanent magnet
   generator are dependent upon the type of magnetic
   material utilized during operation and storage, and
   the influences which tend to demagnetize the magnets.
   These influences include temperature, vibration, stray
   magnetic fields and the opposing magnetic field created
   by the generator load current (Lenz's Law) which is at
   a maximum when the generator is short circuited.

   Coercive force (H_c) alone is not a sufficient indication
   of a magnet's ability to resist irreversible demag-
   netization. That is because the coercive force varies
   with temperature and also does not indicate the
   irreversible loss of magnetism when a magnetic
   material is shocked by a demagnetizing influence.

   These effects can best be determined by subjecting the
   generator to overload and repetitive short circuit tests.

   c-1.   Terminal Voltage and Phase

      Commercial permanent magnet power generators
      are available for 60 cps up to 15 kva in the follow-
      ing choice of voltage and phase:

Phase	No. Wires	Rated Terminal Voltage
1	2	115V
3	4	120/208

c-2. Voltage Regulation

This is quite sensitive to power factor of the
load. At unity power factor, inherent voltage
regulation is about $\pm$ 5%. At a 0.8 power factor
lagging, the inherent voltage regulation degrades
considerably to over $\pm$ 11% for some units.
Static voltage regulators are available at extra
cost which will maintain $\pm$ 2% with a 0.8 lagging
power factor. Waveform distortion is in the
range of 3% to 5% harmonic content.

c-3. Frequency Regulation

This is dependent upon the speed regulation of
the prime mover and is comparable to the other
generator types.

c-4. Speed

Both 2-pole (3600 rpm) and 4-pole (1800 rpm)
generators are available for 60 cycle power
generation.

c-5. Exciters and Field Control Methods

No exciters are requird and consequently the
permanent magnet field cannot be controlled as
in other types. This is a contributing factor
to the poor voltage regulation exhibited with
low power factor loads.

c-6. Insulation and Temperature Rise

Class A insulation is generally provided with a
40°C temperature rise specification.

c-7. Short Circuit and Overload Capacity

Commercial permanent magnet generator
literature specifies a 25% to 30% overload
capacity. Some manufacturers claim their
units will withstand prolonged short circuit
operation without impairment or dangerous

overheating, but magnet manufacturers show an
irreversible loss for practically all magnetic
materials subjected to a coercive force equal
or greater than the value required to drive the flux
density to zero. The effect of repeated short
circuits upon further loss of magnetism is also
not specified.

c-8. Enclosures

Available enclosures include the drip-proof,
splash-proof and totally enclosed.

c-9. Efficiency

Commercial literature does not specify the
efficiency, but it appears to be comparable
to the other types.

C. Summary

1. Drip Proof and Splash Proof Enclosures

The rotating armature generator is the least expensive of
the commercially available generators in the 5 kilowatt
power range, exhibits inherently good voltage regulation
over a wide power factor range, is self excited to eliminate
the need for an external field excitation battery, shows
high efficiency and is readily available in drip-proof and
splash-proof enclosures.

A principal problem with the self excited rotating armature
generator with a dc exciter is the temporary loss of
residual magnetism in the soft iron exciter core when the
generator is inactive for long periods such as a month to
six months or longer.

A principal problem with the self excited rotating armature
generator with a permanent magnet exciter is the permanent
reduction in residual magnetism during long periods of
storage and the demagnetizing influences during operation.

Loss of residual magnetism causes failure of the exciter
to build up sufficient voltage for the generator field in
the case of the permanent magnet exciter or no voltage
for the generator field in the case of the dc exciter.

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There is no remedy for the permanent magnet exciter.
There are simple remedies for the dc exciter temporary
loss of magnetism.

Remedies for the dc exciter loss of magnetism include
exercising the generator at frequent weekly or bi-monthly
intervals to prevent loss of magnetism, or after longer
storage periods, a well-charged storage battery can be
briefly electrically connected to the exciter field with
the correct polarity to re-establish the residual magnetism
in the core.

Another alternative is to utilize a storage battery and
rheostat as field supply for the generator and eliminate
the generator exciter. In this case, electrical power
for the shelter is entirely dependent upon the storage
battery condition. When inactive for long periods of
time, the dc exciter is also dependent upon storage
battery condition for restoration of residual magnetism
in the core.

To eliminate absolute dependence upon storage battery
condition and insure continued full power output of the
generator, weekly or bi-monthly exercising of the
rotating armature generator at rated electrical load
conditions is recommended.

Periodic exercising of the prime mover and generator
ensures that residual magnetism for proper voltage
buildup is retained and that excessive buildup of air
borne dust and dirt, insect and small animal debris,
moisture and oxidation deposits on brushes and slip or
split rings are inhibited or removed by the ventilating
media.

VIII. CARNOT-CYCLE-LIMITED DEVICES

A. Introduction

In a previous study (C1) a survey was made on the cost of generating electric power by the newer conversion devices in order to determine whether or not there was any advantage in replacing conventional engine-generator sets by these newer conversion methods. The conclusion reached was that engine-generator sets (available in kilowatt sizes) have an initial cost at least 100 times lower than any of the newer devices (available only in watt sizes).

The engine-generator set does have several disadvantages such as the following:

1. A highly-refined, liquid fuel is normally required.

2. The unit may not be reliably placed into operation after a 10-year, static-storage period by unskilled personnel.

3. Fuel and attention are required for exercising the engine during storage.

It may seem strange that internal-combustion engines are not classified as Carnot-cycle limited devices in view of the extensive use of air-standard analysis (A1). However, a recent paper (C9) clarifies this by classifying engines as Q-engines, which <u>require</u> that the internal energy of the fuel be first converted to heat and operate the working fluid through a cycle (thus Carnot-cycle limitations) and E-engines, which do not require that the internal energy be converted to heat and operate in theory with a process (thus no Carnot-cycle limitations). Q-engines represent Rankine-cycle, Stirling-cycle, and thermionic devices, while E-engines include internal-combustion engines, fuel cells, and living organisms.

Some recent success (C1) in adapting closed-cycle, Rankine-cycle turbines and reciprocating engines using a heavy-molecular-weight working fluid or steam respectively suggested that this type of power producer may offer the following advantages for shelter application:

1. Cheap, readily available, easily stored, solid fuels may be used as well as the more highly-refined fuels.

2. If the unit was hermetically sealed, several available working fluids are noncorrosive (in the absence of oxygen) for a considerable period of time.

3. The system could be made relatively foolproof with a minimum of moving parts such that unskilled personnel would be required to do little other than firing a furnace.

4. While it is true that steam in a cylinder would require rust resistant materials, the corrosive action should be less severe than that due to combustion products in an internal-combustion engine.

Although the most optimistic of the small Rankine-cycle devices reported showed a computed ideal thermal efficiency (exclusive of the combustion and boiler efficiencies) of approximately 15 per cent (compared with 40 per cent overall thermal efficiency for large central-power stations), it was concluded that this unit offered more promise for shelter application than the Stirling engine, which is highly efficient in small sizes under laboratory conditions, because of less severe storage requirements and necessary operator skills. All external-combustion engines would present similar problems in the design of a combustion chamber suitable for burning solid fuels.

This section details the thermodynamic analysis of an impulse turbine and offers preliminary design of the components of a complete system consisting of a turbine-generator unit, solid or liquid fuel combustion chamber, boiler, and con-denser. Also, a preliminary design of a reciprocating-engine, steam unit is included. Cost data are included wherever available.

B. Thermodynamic Analysis of a Rankine Cycle with a Turbine Prime Mover

A detailed thermodynamic analysis of the cycle utilizing an impulse turbine as the prime mover is presented in texts (C2) and other sources previously reported in reference C1. The pertinent equations are included here and an analysis of the unit selected for preliminary design is included.

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A useful thermodynamic diagram for analysis of turbine per-
formance and determination of thermal efficiency of a vapor
power cycle is shown in Figure C1. This pressure-enthalpy
chart is usually available from the manufacturer of the work-
ing fluid to be utilized or it may be constructed from thermo-
dynamic data.

Two types of cycles may be represented on the diagram: a
subcritical cycle or a supercritical cycle. Both cycles are
shown on the diagram in Figure C1, but only the super-
critical cycle will be detailed since this was selected for
preliminary design.

The working fluid may be considered as saturated liquid at
point 1. The liquid is pumped (nearly isentropically, i.e.,
without inefficiency or heat loss) to a high pressure by means
of a liquid feed pump to point 2 where it is heated to point 3
by means of energy available in the hot turbine exhaust. A
shell-and-tube heat exchanger is satisfactory for this purpose.
The working fluid next enters a boiler and is heated at
essentially constant pressure to point 4 where it is super-
heated vapor. Point 4 also represents conditions at the
turbine inlet.

The high-temperature, high-pressure, working-fluid vapor
is next allowed to expand to a lower pressure through the
nozzle of an impulse turbine. The high velocity gas that
issues from the nozzle ex'' does useful work on the turbine
wheel and leaves ideally (isentropic process) at point 5.
However, due to friction and other effects the final state
of the working fluid will be at point 5'. The hot, low-pressure,
superheated vapor leaving the turbine housing flows through
the shell side of the heat exchanger (where the liquid is
heated in tubes on its way to the boiler) and leaves at point 6.
It is next cooled in a condenser and condensed to saturated
liquid at point 1. The heat that must be transferred out of
the system in order to condense the working fluid is either
carried away by atmospheric air or well water (if available).
The saturated liquid at point 1 then returns around the cycle.

A block diagram showing the arrangement of the required
components is presented in Figure C2.

CRITICAL POINT

LIQUID

PRESSURE

SUPERHEATED VAPOR

WET VAPOR

ENTHALPY

a. SUBCRITICAL CYCLE

500 PSI.

400°F

PRESSURE

64 PSI.
120°F

20%
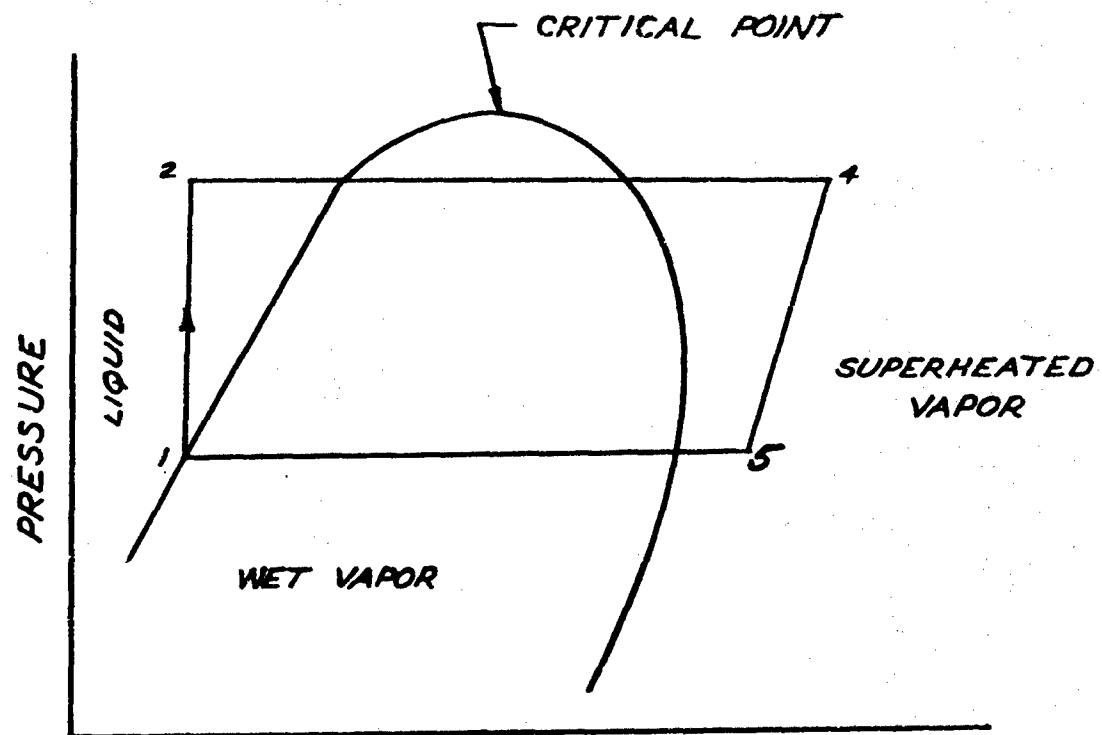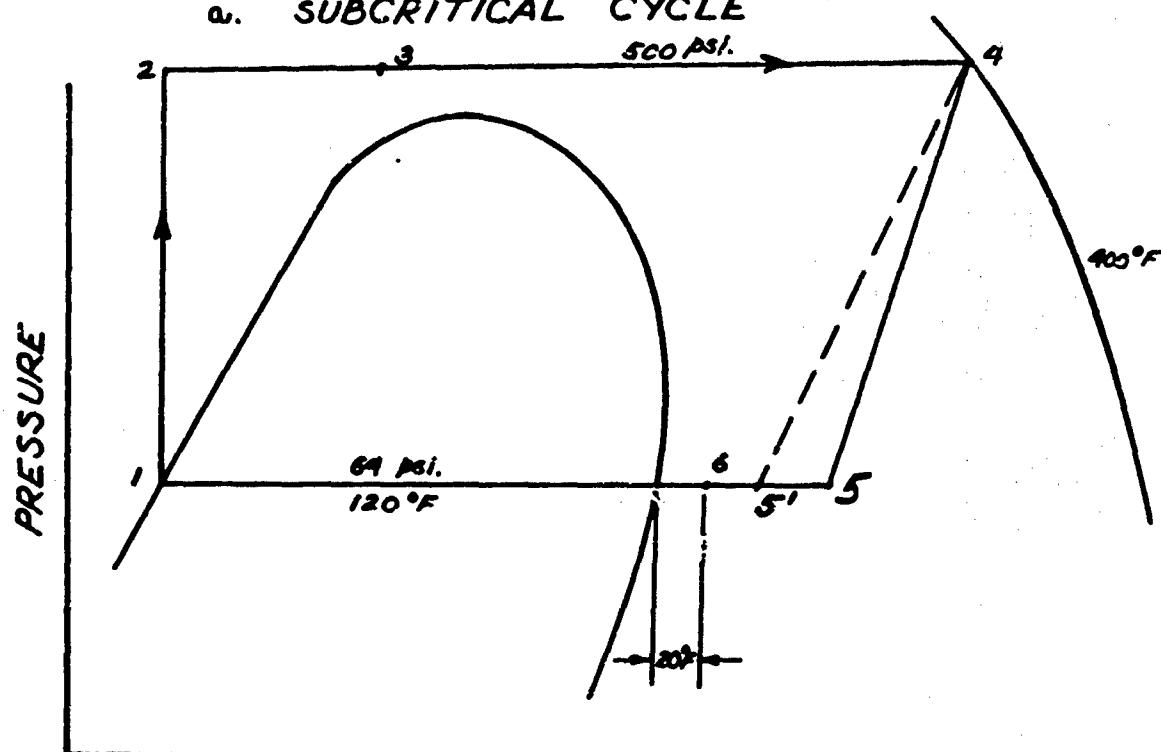
ENTHALPY

b. SUPERCRITICAL CYCLE

FIG. CI PRESSURE - ENTHALPY
DIAGRAMS FOR A VAPOR POWER CYCLE

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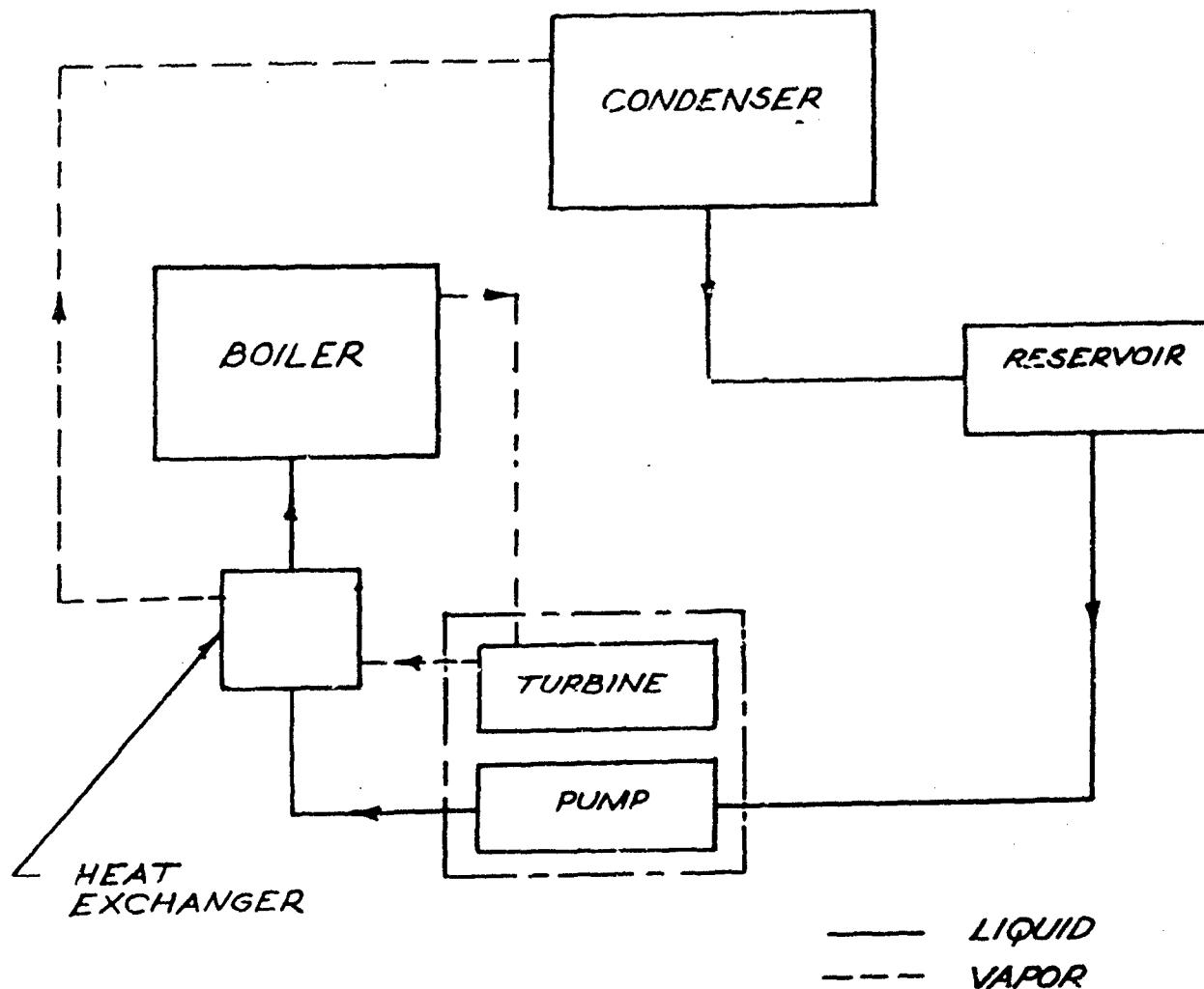
FIG. C2   COMPONENTS & FLOW DIAGRAM
FOR A VAPOR POWER CYCLE

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The thermal efficiency of the Rankine cycle is defined as
the net work output of the turbine wheel minus the work
required by the feed pump divided by the heat which must
be added to the fluid in the boiler. It is obvious that the
heat exchanger will decrease the heat that must be added
in the boiler since the liquid working fluid is heated on its
way to the boiler by cooling the hot exhaust steam on its
way to the condenser. An apt name for this component
is a "feedback" heat exchanger. However, this increase in
thermal efficiency must be accompanied by increased
first cost.

The objective is to obtain as high a thermal efficiency as
possible in order to reduce the fuel requirements, but this
goal is severly limited by the following considerations:

1. The available condenser temperature is limited by the
    temperature and type of "heat sink" fluid available
    (hot outside air as opposed to cold well water) as well
    as the surface area of the condenser.

2. The upper temperature allowable in the boiler is limited
    because the resulting higher pressure requires exces-
    sive wall thickness; the fluid is subject to thermal
    decomposition at high temperature; and multistage
    liquid feed pumps may be required to pump the fluid
    to boiler pressure.

3. It is quite difficult to design a simple, cheap turbine
    wheel that can utilize the available energy of an
    arbitrary, high-temperature working fluid and yet
    operate efficiently at a reasonable wheel speed.

Although modern central-power stations utilize multiple
stage turbines, the smaller horsepower machines (1-20 hp)
are usually single-wheel impulse types to provide simplicity
in design. The wheel speed is usually limited because of
material strength limitations and the excessive windage
losses at high speeds. For this reason a modern trend is
to use a high-molecular-weight organic fluid to allow high
temperature operation and low wheel speeds.

The ideal available energy for useful work in the turbine is
shown in Figure C1 as the enthalpy difference between points

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4 and 5'. This enthalpy change through a nozzle produces a gas velocity (V_O) which is directed at the turbine blades. Assuming a negligible velocity for the fluid as it enters the nozzle from the boiler, the actual nozzle exit velocity is given as -

$$V_o = 223.8 \ K_n \sqrt{h_4 - h_{5'}} \qquad \text{(ft/sec)} \qquad \text{C1)}$$

where K_n is the nozzle coefficient (approximately 0.95)

h_4 and $h_{5'}$ are the enthalpies per pound of fluid at points 4 and 5' respectively (Btu/lb)

It is shown (C2) in the literature concerned with turbine design that the ideal peripheral velocity of the turbine blade row should be 0.47 that of the nozzle exit velocity for a single-stage impulse turbine. Hence, the turbine wheel diameter (D ft) required for the turbine to operate at N rpm for a given "enthalpy-drop" through the nozzle is given as -

$$D = 60 \ (0.47 \ V_o) \ / \ (\pi \ N) = 1905 \sqrt{h_4 - h_{5'}} \ /N \qquad \text{C2)}$$

It can be seen that small diameter, efficient turbines are inherently high-speed devices.

The isentropic enthalpy-drop that produces the high velocity gas stream is not fully recoverable in useful work because of the following major losses:

1. Nozzle losses due to nonisentropic expansion

2. Blading losses due to fluid friction and disturbances.

3. Disk friction as the turbine revolves in vapor.

4. Bearing, gearing, governing and other mechanical losses.

In addition, pump work requires a considerable fraction of the work produced by small-horsepower turbines utilizing high-molecular-weight working fluids.

Many possible parameters that may affect turbine operation were considered in the detailed study referred to above. In this section only the "best design" conditions will be

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The work required (W_p Btu/lb) to pump a pound of saturated working fluid from condenser pressure to boiler pressure (ΔP psi) is given as -

$$W_p = 144 (\Delta P)/(778 \rho_f e_p) = 0.463 \Delta P / \rho_f \qquad C6)$$

where ρ_f is the density of the saturated working fluid as it leaves the condenser (lb/cu. ft.)

e_p is the pump efficiency (assumed to be 0.4)

Thus the flow rate of working fluid (M_f lb/sec) to produce a desired shaft horsepower output (H_s), if the mechanical efficiency is e_m (due to bearings, gears, etc.), is given as -

$$M_f = H_s/e_m \left\{ 1.415 \left[e_n e_b(h_4 - h_5') - W_p \right] - H_d \right\} \qquad C7)$$

It was discussed earlier that the major losses are due to nozzle, blade, and disk inefficiencies. These losses will increase the enthalpy of the fluid entering the heat exchanger from the isentropic point 5' to a constant pressure value at a higher entropy, point 5. This assumes that there is negligible heat loss through the turbine housing. Thus

$$h_5 = h_5' + (1 - e_n e_b)(h_4 - h_5') + 0.707 H_d/M_f \qquad C8)$$

Not all of the enthalpy difference of the fluid between point 5 and point 6 may be used to increase the enthalpy of the liquid from point 2 to point 3, since some of the heat may be lost through the wall of the heat exchanger. If we let the heat exchanger efficiency be e_{he}, the required heat addition to the liquid in the boiler is given as -

$$Q_b = M_f(h_4 - h_1) - e_{he} M_f(h_5 - h_6) \qquad \text{Btu/sec} \qquad C9)$$

where the second term on the right of Eq. C9 may be termed the feedback heat transfer (Q_{fb}). Eq. C9 is a conservative statement of the boiler requirements since a portion of the pump work required to increase the fluid pressure to boiler conditions will increase the enthalpy of the fluid.

The thermal efficiency of the cycle may be stated as -

$$e_t = 0.707 H_s/Q_b \qquad C10)$$

Several working fluids were examined to determine their
suitability for a hermetically-sealed, turbine-generator
set. The thermodynamic characteristics of these working
fluids are presented in Table C1. The vapor pressure of
the working fluid at 45°F (assumed shelter temperature
during storage) is an important parameter because if it is
below atmospheric pressure, air may leak into the unit
during periods of long storage. This would induce cor-
rosion and change the thermodynamic characteristics
during operation. Outward leakage of a minute amount of
working-fluid vapor could be compensated for by providing
a larger original charge. The critical temperature and
pressure indicates whether or not the chosen vapor cycle
will be supercritical and indicates the range of pressures
to be encountered within the system for a proposed cycle.
The molecular weight of the working fluid is an important
factor with a single-wheel impulse turbine since the nozzle
exit velocity is reduced (for a given enthalpy-drop) as the
molecular weight is increased. This results in lower
required wheel speeds and yet maintains an optimum ratio
of blade speed and nozzle exit velocity for small diameter
wheels.

Several tentative cycles utilizing the working fluids in
Table C1 were constructed and the above analysis was
used to compute the wheel diameter - RPM relationship,
fluid flow rates, thermal efficiency, and feedback heat
exchanger effect on thermal efficiency. The results of
this investigation are tabulated in Table C2.

New symbols not previously defined are the following:

T_b is the temperature of the working fluid
as it leaves the boiler (F).

P_b is the selected boiler pressure (psia).

T_c is the temperature of the saturated liquid
as it leaves the condenser (F). This
essentially fixes the lowest pressure in
the unit

P_c is the vapor pressure of the saturated
liquid from the condenser (psia).

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TABLE C1

Properties of Various Organic Working Fluids

Fluid	Vapor Pressure at 45°F (psia)	Critical Temp(°F)	Critical Pressure (psia)	Molecular Weight	Comments
Monochloro-benzene	0.048	680	655	112.6	Flammable as kerosene
Freon 11	7.85	388.4	635	137.38	Non-flammable
Freon 21	13.75	353.3	750	102.93	Practically non-flammable
Freon 114	16.9	294.3	474	170.9	Non-flammable - One of the lowest Freon decomposition rates.

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TABLE C2

Performance of Rankine Cycle with a Turbine Prime Mover

Working Fluid	T_b	P_b	T_c	P_c	D	N	h_1	h_4	$h_{5'}$	h_6	ρ_g	$Mg \times 10^5$
Water	150 (Sat. Vapor)	3.72	120	1.69	1.0	13,450	87.9	1126	1076	--	0.005	3.8
Monochlorobenzene	300 (Sat. Vapor)	22	120	1.0	1.0	12,100	6.7	207.32	167.0	163.22	0.0092	0.32
Freon 21	360	500	120	56	1.0	9,620	39.5	159	133.5	136.5	1.0	0.81
Freon 114	300	500	120	64	1.0	6,550	37.3	105.8	94	91.5	1.72	0.82
	450	500	120	64	1.0	7,970	37.3	142.5	125	91.5	1.37	0.82
	400	500	120	64	0.5	15,240	37.3	131	115	91.5	1.45	0.82
	400	500	120	64	1.062	7,200	37.3	131	115	91.5	1.45	0.82

Working Fluid	ρ_f	H_s	C	H_d	W_p	M_f	h_5	Q_{fb}	Q_b	e_t
Water	61.7	10	.06	1.06	0.0152	.21	1081 (wet)	--	218	.0324
Monochlorobenzene	67.2	10	.0445	0.105	0.145	.237	175.87	3.25	44.6	.1586
Freon 21	81.54	10	.0221	2.84	2.52	.482	143.1	2.55	55	.1285
Freon 114	86.08	10	.0214	1.495	2.35	1.28	97.39	6.03	81.7	.0865
	86.08	10	.0209	2.09	2.35	0.752	130.78	23.6	55.6	.127
	86.08	10	.0247	0.573	2.35	0.763	119.02	16.76	54.74	.129
	86.08	10	.0212	2.24	2.35	.868	120.32	20.0	61.2	.1155

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A heat exchanger having an efficiency of 0.8 was assumed for all calculations. The heat exchanger was assumed capable of cooling the exhaust vapor from the turbine blade exit temperature to 20°F above the saturated vapor (and liquid) temperature at condenser conditions.

The conclusions drawn from Tables C1 and C2 are as follows:

1. Water as the working fluid is completely unsuitable for a small, single-wheel, turbine-alternator set.

2. Monochlorobenzene provides an extremely attractive thermal efficiency, but its low vapor pressure may cause severe leakage of air into the unit during storage. Also the working fluid is quite flammable.

3. The most satisfactory Freon compound from a storage, thermal efficiency, and thermal stability point of view is Freon 114.

4. The most attractive operating speed for the turbine is 7200 rpm with a wheel of approximately 1 ft. diameter.

The thermodynamic cycle, working fluid, and turbine diameter chosen for preliminary design are given in the last line of Table C2. The boiler temperature of 400°F was chosen to insure reasonable thermal stability and the 500 psia boiler pressure appears to be a reasonable requirement with a double-stage, high-speed turbine feed pump.

Numerous attempts (C1) have been made to build small, efficient, steam-driven devices. The most satisfactory prime mover has been a reciprocating engine with an over-all thermal efficiency of the cycle of about 5 per cent. Efforts to use reciprocating steam engines are continuing (C10). However, most of these investigators are not concerned with long term storage and operation by inexperienced personnel.

C. Preliminary Design of A Complete System Utilizing a Turbine-Alternator Unit

1. Combined Rotating Unit

Modern practice in design of hermetically-sealed, turbine-alternator units for space satellite operations involves a "combined rotating unit" (CRU) in which the turbine, alternator, governor, and boiler feed pump are encased in a sealed housing and preferably mounted on a single shaft. This necessitates matching components that are all able to operate efficiently at the same speed and assumes that the frequency of the electric power output is satisfactory.

A CRU for shelter application is shown in Fig. C3. The unit is to be operated at 7200 rpm and produces 5 KW of 120 cps, 230 volt, electric power. The major components on the single shaft are (1) turbine wheel, (2) governor mechanism, (3) exciter, (4) 120 cps brushless alternator, and (5) turbine-type centrifugal pump.

The Freon-114-working-fluid vapor from the boiler enters the hermetically-sealed housing and is partially throttled by the speed-control-governor mechanism and then flows to 2 nozzles near the periphery of the turbine blades at the uppermost part of the CRU casing (where no bearing surfaces are exposed) and follows two parallel paths through the shell side of 2 shell-and-tube heat exchangers. The vapor is cooled by the saturated liquid flowing through a multitude of small tubes. A pressure drop through the shell side of the heat exchanger (approximately 10 psia) will change the operating conditions slightly from those computed in tabulated Table C-2.

The cooled exhaust vapor passes between the rotor and stator of the alternator and cools this unit. The super-heated vapor then flows to the condenser where it rejects heat to atmospheric air or well water. The returning saturated liquid is pumped to boiler pressure level by a turbine-type, centrifugal pump located on the lower end of the CRU shaft, flows through the tubes of the two parallel heat exchangers, and enters the boiler.

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LIQUID TO BOILER

HOT EXHAUST VAPOR

TURBINE   WHEEL

NOZZLE

GOVERNOR

THROTTLE

VAPOR FROM BOILER

FEEDBACK
HEAT
EXCHANGER

FEEDBACK
HEAT
EXCHANGER

VAPOR TO CONDENSER

ALTERNATOR

EXCITER

BEARINGS

PUMP

SATURATED
LIQUID
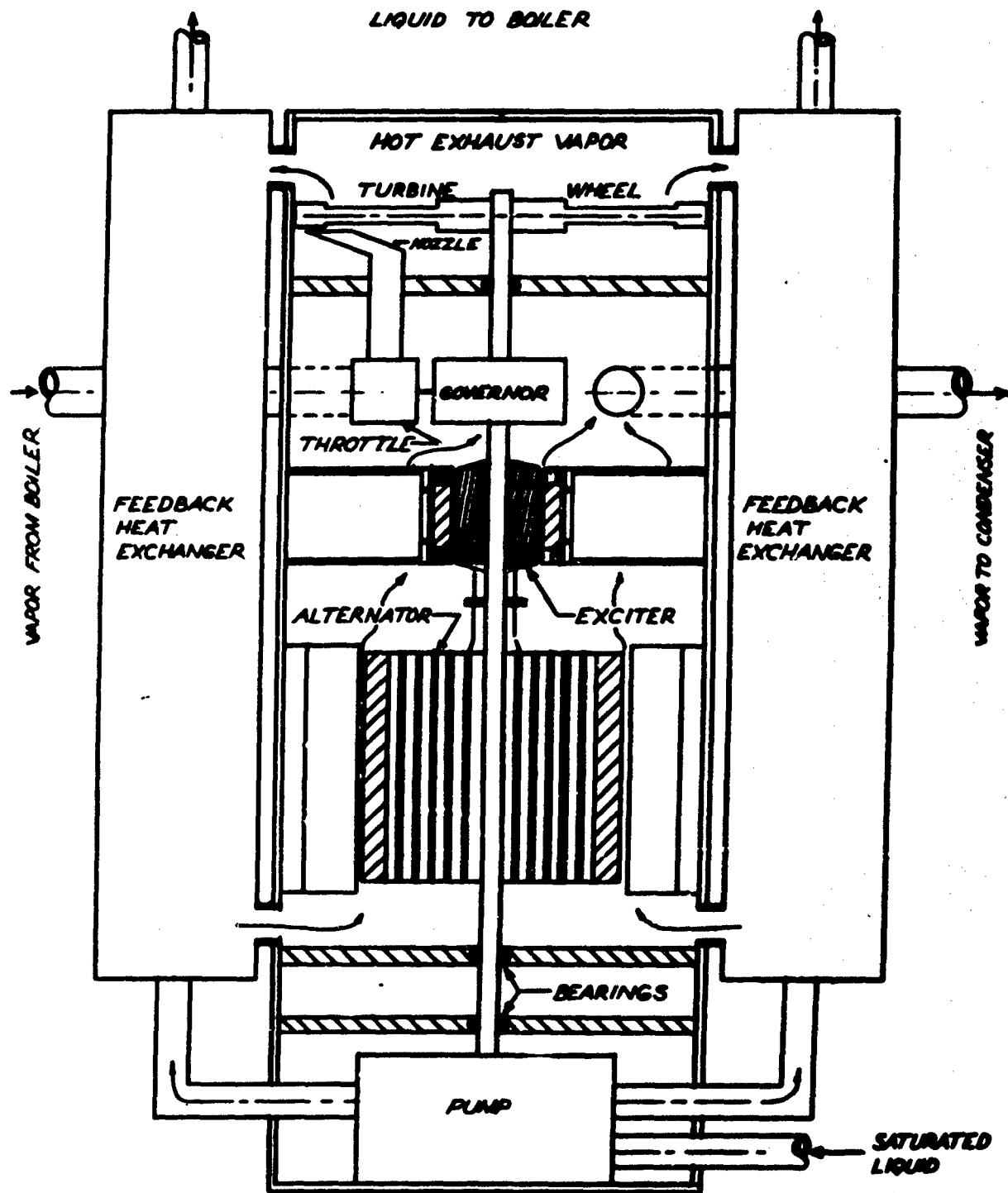
FIG. C3 COMBINED ROTATING UNIT

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Much thought was given to the decision to eliminate gear reducers within the CRU by use of a 2-pole alternator developing 120 cps electrical power. Since the shelter and its equipment will be specialized, a decision was made that elimination of the gear reducer was worth the disadvantages of 120 cps power. Gear reducers usually require copius supplies of lubricant and unnecessary contact of Freon compounds with lubricants should be avoided since this accelerates thermal decomposition. A more detailed discussion of the utilization of 120-cps power is presented later.

The turbine feed pump may be manufactured with present technology, but extremely close tolerances between the turbine wheel and the pump housing (0.001 in. is common) requires accurate axial positioning of the CRU shaft. The technique suggested by most pump manufacturers involves 2 bearings that are preloaded and accurately located with respect to the CRU housing. An alternate scheme (not commonly used) may be to have a graphite thrust bearing in the pump housing on the end of the CRU shaft with one preloaded bearing outside of the pump. An estimated cost of a satisfactory pump (C3) is $200 in lots of one hundred units.

Since the lubricity of Freon is very poor, the bearings should have lubricant seals to minimize the contact of working fluid with the lubricant used. Lubricants that appear to be compatible with Freon 114 are marketed. However, there is evidence that a lubricant that is stable at 400F and Freon at 400F may result in serious thermal decomposition when placed in contact with each other at 400F.

One of the primary purposes for considering the Rankine cycle as a power cycle for shelters was to eliminate the necessity of weekly exercising as with engine-generator sets. The CRU shown in this section should be quite satisfactory for static storage. However, the lubricant seals on the shaft at the ball bearings as well as the necessary packing on the shaft as it enters the feed pump may require an occasional rotation of the shaft. However, a bypass arrangement such that liquid is not pumped into a cold boiler would be required or very slow rotation of the turbine. This could be accomplished

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by adding a motor winding to the alternator. The alternator has no brushes to cause difficulty.

An estimated cost of the alternator (with exciter) would be approximately $500 in lots of 100 units. The type of feedback heat exchangers required for this application should be approximately $400 each in lots of 100 units. Hence, the cost of the CRU would be at least $2,000.

2. Fuel and Storage System

    a. Selection of fuel

    Since the type of solid fuel used in one locality may not be suitable in another locality because of economic reasons, Southern Illinois bituminous coal was selected as a typical solid fuel for the shelter application. Another reason for its selection is its similarity to other bituminous coals from other sections of the country having a high percentage of volatile matter. In general, with the exception of the anthracite coals, the equipment design, with slight modifications, could be adapted to use coal from all sections of the country. Since bituminous coals are plentiful and are georgaphically located in many sections of the country, shipping costs should be kept at a minimum. Highly-volatile bituminous coal has had an average heating value of approximately 12,000 BTU/pound (as received) and is easy to ignite, free burning, and burns with a characteristically long flame.

    It has several disadvantages, but these can be overcome, or at least lessened, by the proper procedures. Among these disadvantages is its tendency to spontaneously ignite. This can be overcome by suitable storage methods. One such method will be mentioned later.

    Since furnace efficiency is directly proportional to the frequency of firing per unit time, achievement of high efficiency requires relatively small quantities of fuel to be fired at short intervals of time

(1-2 hours). If contaminated air is being used for combustion, these frequent firings may necessitate some type of protective clothing for the fireman.

Another disadvantage, which can be eliminated, is that much smoke and soot are possible if the furnace is improperly fired. This is especially true at low burning rates.

The size of the coal should either be stove (1-5/8" - 2-7/16") or nut (13/16" - 1-5/8"). The fines should be removed and the coal should be dry. A double-screening will minimize the effects of segregation (segregation is a contributing factor to spontaneous combustion).

The amount of coal needed to continuously generate 5 KW for the three week period (504 hours) is 15,000 pounds, and 3000 pounds of coal are added as a safety factor, bringing the total amount of coal stored to 18,000 pounds (9 tons). The coal should be stored in a bin of 450 cubic feet capacity. A cylindrical storage bin 8 feet in diameter and 9 feet deep would be of sufficient volume but its actual construction might be difficult to achieve. Therefore, a 7 foot hole. 8 feet square is a possible alternative.

This coal is to be kept inside a 10 mil thick poly-ethylene bag which is placed in the hole after it has been dug and shored-up with wooden planks. Since one recommendation is to keep the coal dry, the filling of this bag should not be done on a rainy day. The coal can simply be dumped into the polyethylene-lined hole without any precautions. The ten-mil-thick polyethylene liner was selected because its strength is expected to be sufficient to withstand the abrasion which will accompany the filling. When the liner is filled, the sides should be folded over and a plastic or asphalt spray should be applied to seal the container. This will prevent air and moisture from entering the stored

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fuel supply. The bottom of the plastic bag (near the furnace room) should be supplied with a ripcord or other fast-acting means for opening the coal supply when the emergency arises.

The cost of the polyethylene liner is approximately $20.

3. Combustion Chamber for Solid Fuel

a. Grate area

The thermodynamic analysis shown above indicated that in order to generate 5 KW of electric power (assuming a boiler efficiency of 0.8 and a furnace efficiency of 0.7), 350,000 BTU/hr. in the form of chemical energy (coal) must be put into a typical Dutch oven. If the heating value of the fuel is 12,000 BTU/lb, the weight of coal burned per hour must be approximately 30 pounds. Good practice dictates that a reasonable value for the combustion rate is 6 pounds of coal per hour per square foot of grate area. Therefore a grate area of 5 square feet is required. Experience gained in combustion of coal suggests making the grate longer than it is wide; thus the grate dimensions are chosen as 2 feet by 2.5 feet.

b. Furnace volume

It is considered good furnace design practice to allow one cubic foot of combustion space for each 20,000 - 25,000 BTU/hr energy input. Therefore, the volume required for 350,000 BTU/hr would be 17.5 cubic feet. If the distance from the grate to the crown (furnace roof) is 3 feet, the volume ahead of the bridge wall will be approximately 14 cubic feet, and the volume after the bridge wall will be nearly 4 cubic feet. This will be a total of 18 cubic feet, which is within the allowable tolerance for furnace design. Figure C4 shows the pertinent features of this furnace.

The materials used in construction of this furnace are firebrick for the walls and interior structures.

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BOILER

CROWN

COMBUSTION
CHAMBER

OVERFIRE CONTROL
DAMPER

BRIDGE WALL

ASH
PIT
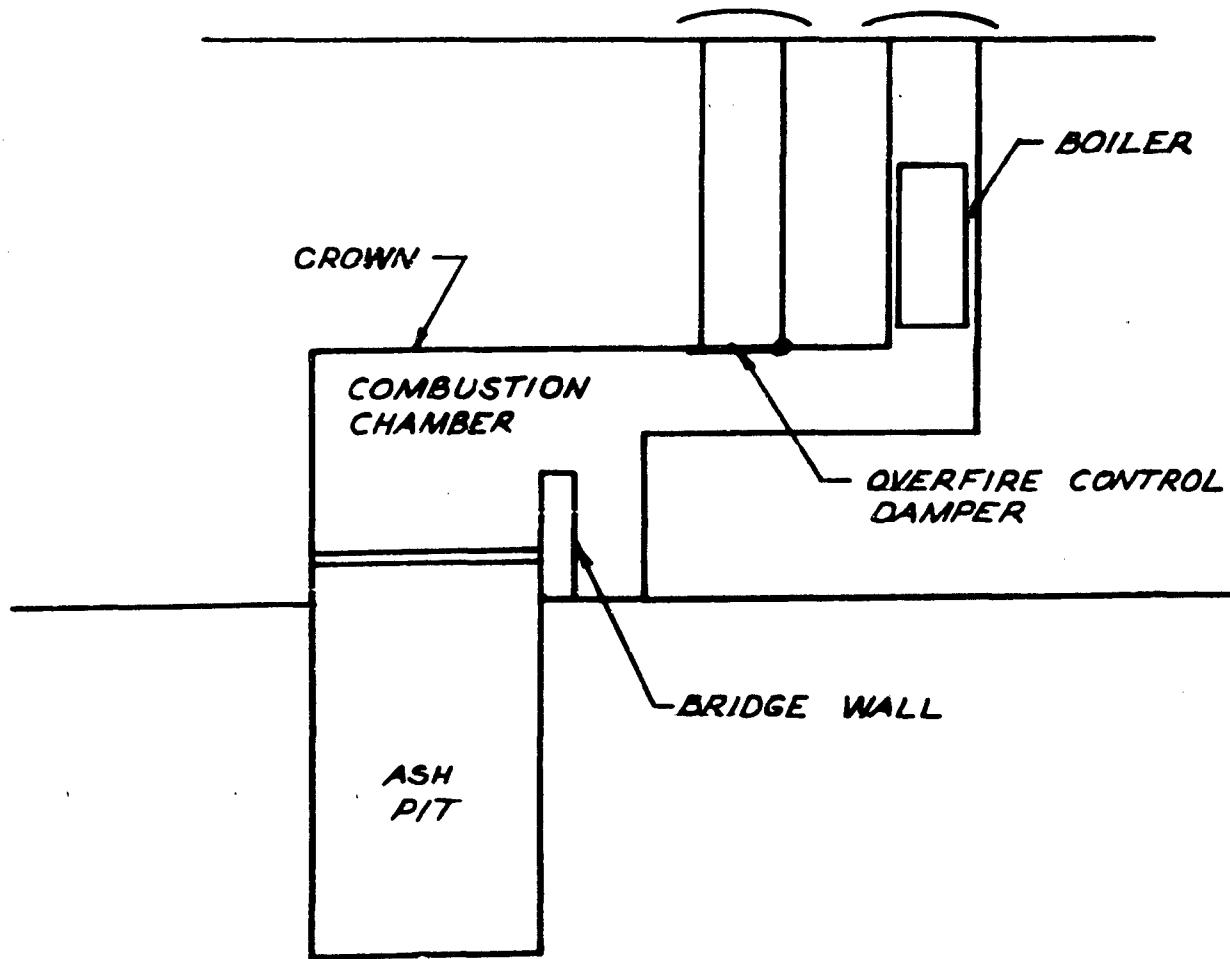
FIG. C4   COMBUSTION CHAMBER FOR
BURNING SOLID FUEL

The doors and grates can be made from cast iron.
The estimated cost of such a unit is $500.

The firing procedure for the furnace in Figure C4
using bituminous coal is actually more a function
of the type of fuel than a function of the type of
furnace; hence, in general, this method is applicable
for firing any furnace with bituminous coals. The
commonly recommended procedure (called the
side-bank method) requires the movement of live
coals to one side or the back of the grate. The
fresh fuel charge is placed on the opposite side.
The results are a more uniform release of volatile
gases, which are ignited by the high temperature
of the red hot coals. Bituminous coal should never
be fired over the entire fuel bed at one time. A
portion of the glowing fuel should always be left
exposed to ignite the gases leaving the fresh charge.

The importance of firing bituminous coal in small
quantities at short intervals is discussed in a
U.S. Bureau of Mines technical paper (C4). Better
combustion is obtained by this method in that the
fuel supply is maintained more nearly proportional
to the air supply.

If the coal is the caking kind, the fresh charge will
fuse into one solid mass which can be broken up
with the stroking bar and leveled from 20 minutes
to one hour after firing, depending on the tempera-
ture of the firebox. Care should be exercised when
stoking so as not to bring ash into the high tempera-
ture zone at the top of the fire, where it will melt
and form clinker. The stoking bar should be kept
as near the grate as possible, and should be raised
only enough to break up the fuel. With fuels re-
quiring stoking, it may not be necessary to shake
the grates since the ash is usually dislodged during
stoking. Adherence to these methods insofar as
practicable will result in better combustion.

The output obtained from any furnace using bituminous
coal will usually exceed that obtained with anthracite,
since bituminous coal burns more rapidly than
anthracite, and with less draft.

In the furnace design presented, provision is made beneath the firebox for the collection and storage of ashes for the entire emergency period. In computing the size of this ash pit, it was assumed that the ash content of the fuel would be 10 per cent of the weight of the coal consumed and that the density of ashes is 45 pounds per cubic foot. Using these values, the volume required would be 40 cubic feet. If the area is 5 square feet (the same as the grate) the depth of the pit will have to be 8 feet below the floor level. The grate is one foot above the floor level to allow the entrance of primary air.

When operating at full load, the furnace should be fired at the rate of about 50 pounds every hour and forty minutes. This procedure should provide the nominal fuel depth of 6 inches and maximum depth of 9 inches.

As shown in Figure C4, the hot flue gases pass through the boiler chamber and are discharged. However, in case of over-firing, the damper drops and deflects the hot flue gases out of the shelter until it is reset.

4. Boiler Utilizing a Secondary Fluid

In the flash (monotube) boiler a supercooled liquid flows through a small diameter continuous tube where it is heated, evaporated and superheated. This boiler, which is used by modern steamcar enthusiasts, seems to be the least prone to explosion due to the absence of large quantities of fluid in the interior of the boiler. It is, however, quite sensitive to fluctuations in the heat source because of the small "thermal inertia" of the boiler.

One major difficulty in many previous studies (C1) utilizing flash boilers is the formation of hot spots on the tube surface especially during initial startup and the resulting thermal decomposition of the working fluid in the flash tube. The thermal inertia of the boiler may be increased by the higher-boiling-point secondary fluid.

A flash boiler design utilizing a secondary fluid considered suitable for the present application is shown in Figure C5. The hot combustion gases from the furnace pass once through the fire tubes and out of the shelter. The secondary fluid may be any fire-resistant fluid having a boiling temperature 500F or higher such as Monsanto Chemical Company's Aroclor 1248, which boils at 644F and has a specific heat equal to 0.27. The vapor that does escape into a reflux column is most likely condensed in the column and drained back into the boiler.

Some type of safety device must be utilized to prevent excessive heating of the working fluid in case of over-firing in the furnace. The simplest method is to incorporate a damper that drops in case of an excessive temperature in the boiler and diverts the hot combustion gases out of the shelter through a second flue (see Fig. C4). The damper may be reset after the overfiring is corrected.

5.   Design of a Freon Vapor Condenser

In order to design a suitable condenser for the vapor power unit, the condition of the Freon as it enters and leaves the condenser must be known as well as the mass flow rate. For the final design condition of the thermo-dynamic cycle presented above, the condenser is required to remove approximately 180,000 BTU per hour with Freon 114 entering superheated at 150F and leaving as saturated liquid at 120F, while the assumed cooling air temperature is 95F and the desired exit air temperature is 110F such that it may be utilized for cooling the furnace room.

Several manufacturers were contacted to indicate the type and size of heat exchanger suitable for this application. The heat exchanger selected (C5) is a crossflow exchanger with 1/2 in. copper tubes with 10 aluminum fins per inch and 3 rows deep. The cross-sectional (face) area is 36.8 sq. ft. (68 by 78 inches). The cost of each unit in lots of 100 would be approximately eight hundred dollars.

Since forced air flow is required with this heat exchanger, a 325 rpm centrifugal blower was selected (from catalog data) to move the required 11,100 CFM of air against a

REFLUX COLUMN

VAPOR TO CRU

SECONDARY FLUID

CONTINUOUS TUBE
FLASH BOILER

LIQUID
FROM CRU

HOT FLUE GASES
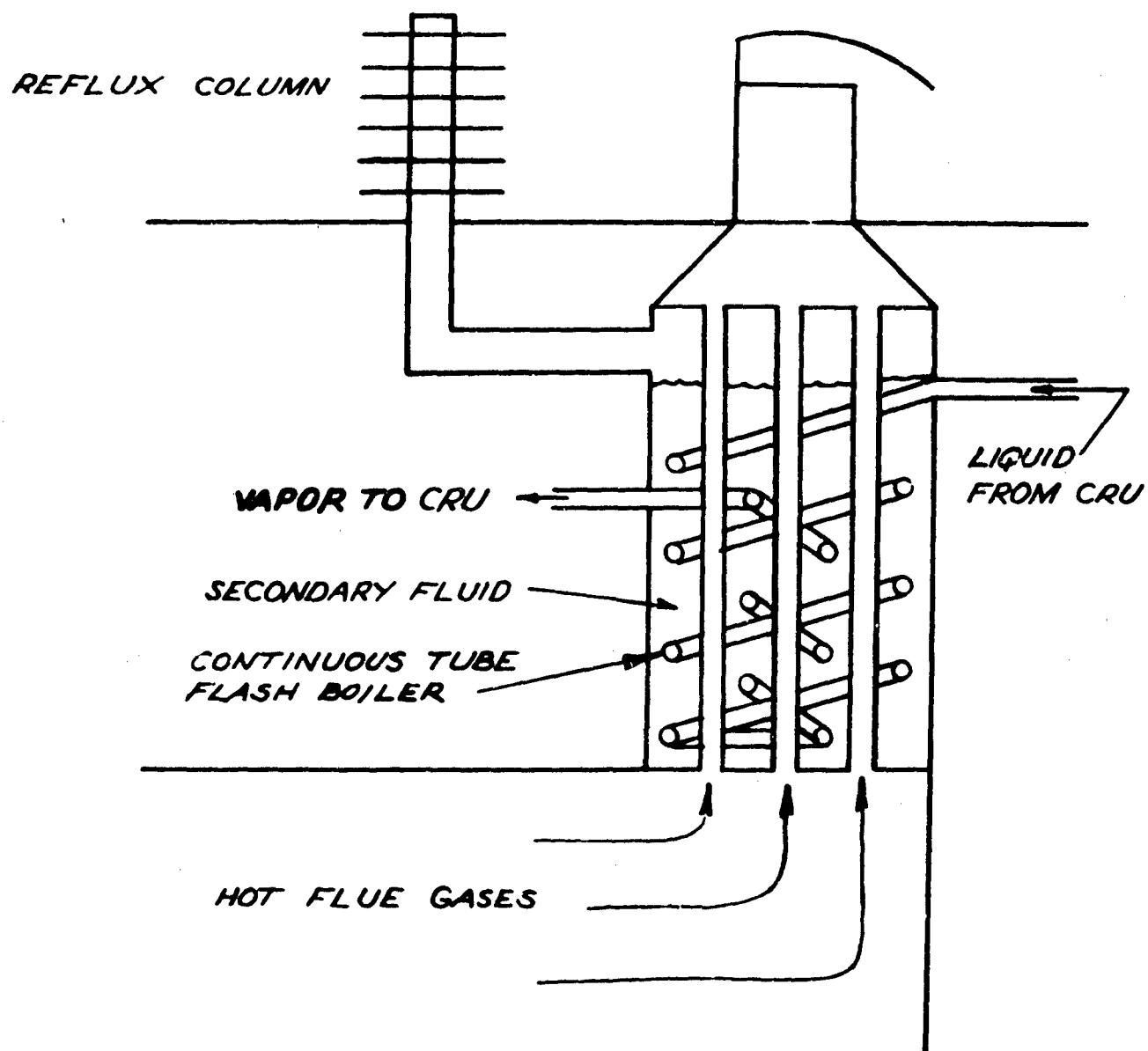
FIG. C5 FLASH BOILER WITH A
SECONDARY FLUID

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2-inch-water-gauge pressure drop through the condenser, the blower requires a 2 hp motor. The price of a suitable blower and motor in units of 100 is approximately one hundred fifty dollars.

6. Flue Gas Rejection

Since a literature search (C1) showed that for the short stack heights anticipated in the shelter application, the maximum natural draft that could be obtained is about 0.1 inches water gauge, the possibility of using some of the condenser cooling air, or shelter air, to provide some forced draft, should be considered.

Since the shelter proper should be at a higher pressure than the furnace room, and the air required for the shelter inhabitants should be nearly equal to that required for the proper combustion of the coal, the shelter air could be throttled to the furnace room and thus provide the necessary draft and air for combustion.

If contaminated air is to be used for the combustion of the fuel, some of the higher pressure shelter air would provide energy necessary for creating draft.

Another possibility would be to use some of the cooling air flowing in the condenser system and vent the proper amount to the furnace for combustion. This would eliminate the need for any separate draft requirement.

If the shelter is maintained at a higher pressure than the fire room, some provision must be made so that the door to the fire room can be opened and closed easily so that the air does not rush into the fire room and disturb the combustion when firing the furnace.

A double door (air-lock) with a means for allowing the air to enter the space between the doors on either side, so that pressures can be equalized, must be provided. These valves must be operable from both inside and outside the compartment.

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7. Over-all System Design

Figure C6 is a diagrammatic representative of the important feature pertaining to the general location of the components of the vapor power cycle.

The shelter proper is isolated, except for the air-lock compartment, from the fire room by a thick wall of earth. This earth will serve to impede the transmission of heat (and radiation dangers) from the fire room to the shelter. In this figure, it is assumed that air from the shelter is used for the combustion of fuel. It is throttled through the walls of the air-lock and in this way provides the necessary draft for proper furnace operation. The coal storage bin is located so that it is accessible from the air-lock compartment; hence, firing of the furnace is done from the air-lock compartment.

The furnace is located in the fire room proper, along with the boiler, which is located within the hot flue gas duct. Part of the air, which is heated in passing over the condenser, can, by means of suitable ducting, be directed over the external furnace walls, and in this way serve to prevent the fire room from becoming excessively heated. After passing over the external furnace walls, this air can be simply vented to the outside. The combustion air, which is coming from the shelter and not confined within a duct, will tend to prevent any contaminated air which may leak into the fire-room from coming in contact with the fireman.

The condenser, boiler, and the combined rotating unit should all be located relatively close to one another so that the piping may be kept as short as possible.

The combined rotating unit is located on a power panel where the necessary controls and indicators are mounted. Access to these controls is gained from the shelter side of the wall.

8. Utilization of Higher Frequency Power

It may be assumed that the primary power loads in the shelter are as follows:

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SHELTER

AIR INLET

CONTROL PANEL
& CRU

A

A

AIR
LOCK

COAL
STORAGE

FURNACE

AIR FLOW

CONDENSER

AIR EXIT

EXHAUST STACKS

BOILER

ASH
PIT
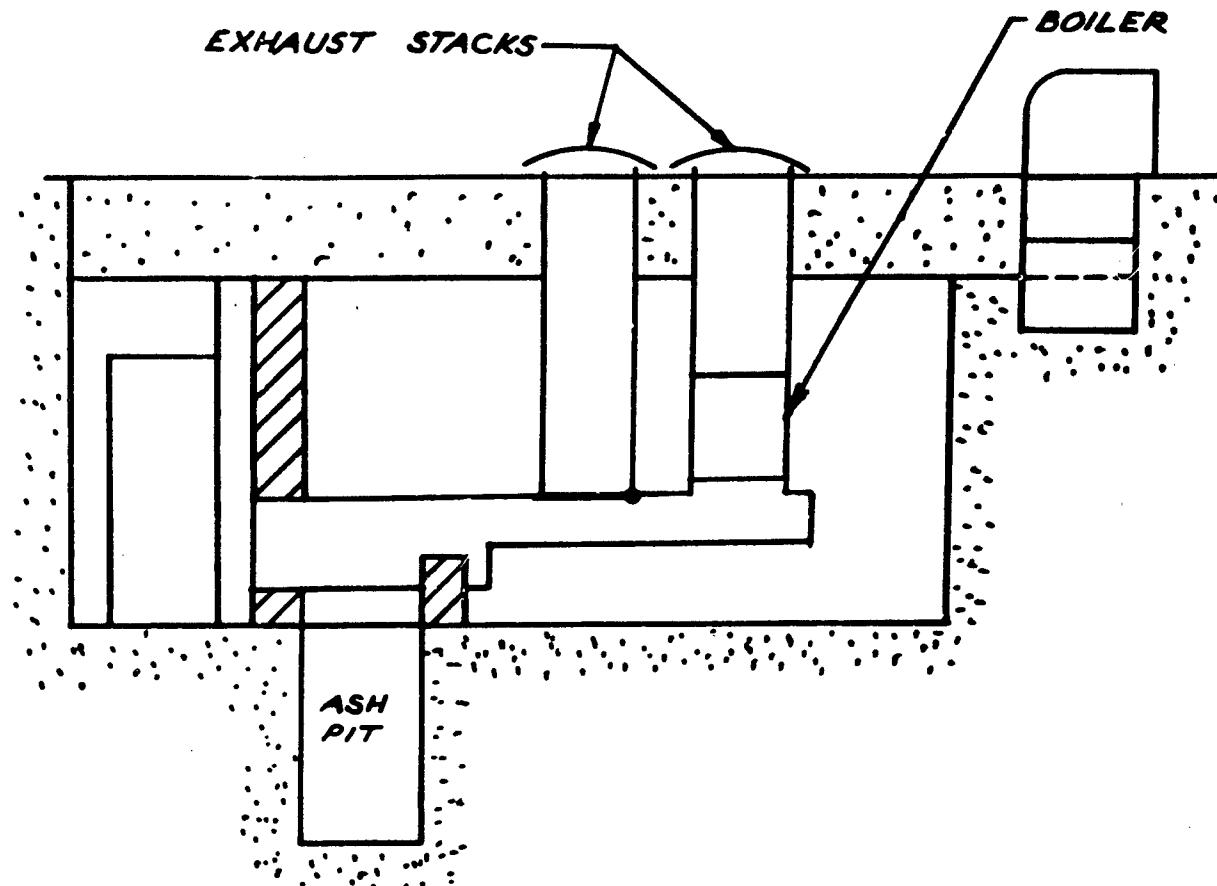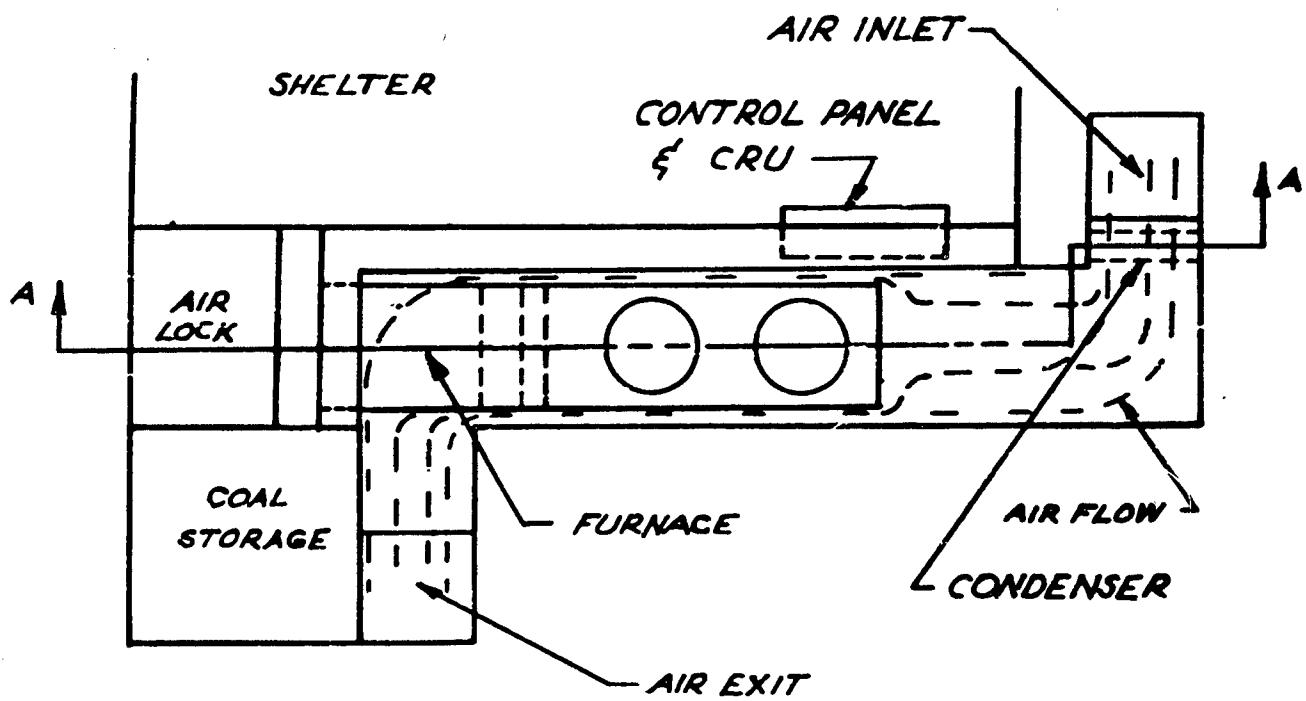
FIG. C6 COMPLETE SYSTEM FOR A VAPOR
POWER CYCLE

P-2711 Pen.

1. Resistive loads such as hot plates and incandescent lights.

2. Direct-current-operated loads such as is possible in communications equipment.

3. Motor loads for various mechanical requirements such as ventilation fans.

The application of 120 cps current to resistive loads and rectification circuits for direct-current power supplies should not offer any particular problems. Many radios that can operate on DC power are available. Hence, the only difficulty in application of 120 cps power would be encountered in motor loads.

An intensive literature search was made and it was found that operation of 60 cps motors at frequencies as high as 400 cps is not new (C6, C7). The results from the literature search may be summarized briefly as follows:

1. An unmodified 1/4 hp, two-pole, 60-cycle, single-phase, 115-volt, squirrel-cage, induction motor operated from a 120 cycle source will require an applied voltage of 230 volts. Asynchronous speed (no load) will be close to 7200 rpm while full rated speed will be about 6950 rpm with a power output of 1/2 hp. Rated load torque and breakdown torque will be about the same as the 60 cycle values, but starting torque will be reduced to about 1/2 of the 60 cycle value. Efficiency will be about 3 to 6 per cent lower. Motor losses will increase about 10 per cent but should be readily removed by the increased fan output which will be about double at the higher speed. Rotor bearing life may be reduced considerably due to the higher speeds (6950 rpm).

2. If it is desired to operate the same type motor at the original speed, four poles must be used and the rotor resistance must be doubled to maintain the original starting torque. The heat rejection rate will be more severe, which may cause some

difficulty since the speed is unchanged. Again the
voltage must be 230 volts and the power output is
1/2 hp rather than 1/4 hp.

D. Preliminary Design of a Complete System Utilizing
A Reciprocating-Engine - Generator Unit

Although the use of a hermetically-sealed turbine-alternator
unit described in the previous section offered a reasonable
possibility of a power unit capable of long term static storage,
it turned out to be several times more expensive than an
equivalent engine-generator set. However, the possibility
of utilizing solid or low grade liquid fuels in an external com-
bustion engine still warranted a cursory examination of the
use of a reciprocating prime mover using steam as the working
fluid in a Rankine cycle. Since it was realized that the overall
thermal efficiency was low, but could possibly be improved by
utilizing high temperature steam, a preliminary layout of a
steam-powered, 5 KW, 60 cps, 115 volt power unit was made
by a consultant with over 20 years experience in designing
and building steam automobiles.

A diagrammatic sketch of the entire layout is shown in Fig. C7.
The boiler is again a monotube (flash) boiler consisting of a
suitable length of 1/2 in. O. D. stainless steel tubing coiled
to make a one-row "water wall" at the bottom and a three-row
tube bank at the top. The secondary fluid is not necessary
since there is no danger of decomposing the working fluid
(water) at the temperatures involved.

The feed water pump is a reciprocating, horizontal unit. It
may be driven in any convenient manner. A solenoid valve
either directs the water into the boiler or back into the con-
densate tank. This solenoid valve is controlled by a thermostatic
sensing element in the steam tube.

The design shown in Figure C7 operates with a liquid-fuel
burner using live steam for delivery and atomization of the
fuel. In the automatic liquid-fuel arrangement, the burner
would be controlled by a switch actuated by the steam pressure.
The usual safety devices to shut off fuel flow unless the hot
exhaust was sensed would be included. For relatively constant
load operation, manual control may be satisfactory.
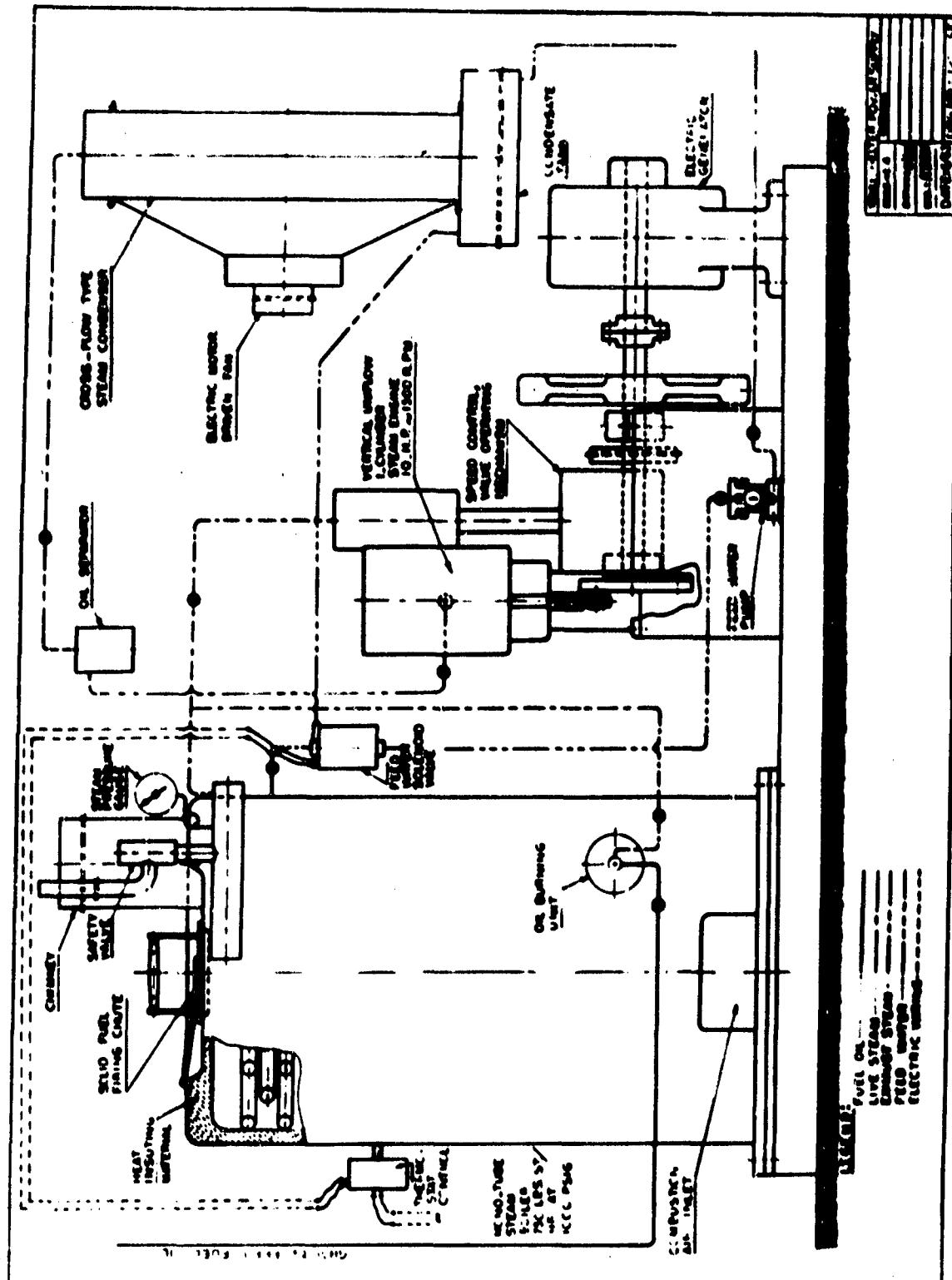
Fig. C 7 COMPLETE SYSTEM FOR A STEAM POWER CYCLE

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Although a central chute for manually firing solid fuel is indicated, this feature has not been checked experimentally. The base of the combustion chamber could be adapted to more conventional solid-fuel combustion chambers.

The reciprocating engine is a single-cylinder, single-acting, uniflow, poppet-valve, steam engine. Its operating speed would be 1800 rpm when driving a 4-pole, 60 cps, AC generator. The exhaust steam passes through an oil separator in order to prevent any lubricating oil from reaching the condenser.

The condenser is similar to the cross flow type presented in the previous section.

An estimated development cost of the unit shown in Figure C7 is $20,000 (C8). However, since the overall thermal efficiency of the device is similar to the turbine-alternator unit and many of the components would be quite similar, it may be assumed that the cost of a satisfactory shelter power supply utilizing a reciprocating steam engine would cost approximately as much as the turbine-alternator unit. The system is not hermetically sealed and static storage would be a problem similar to that encountered with conventional engine-generator sets.

The above unit would be a complete system. However, small reciprocating steam engines are also made by various firms such as Semple Engine Co., St. Louis, Mo. A flash boiler is a relatively simple and safe unit and is being used in very recent power conversion work (C10). Freezing of the water and contamination by oil used to lubricate the piston are some of the problems associated with this system.

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BIBLIOGRAPHY

Engine-Generator Sets

A1   Lichty, L. C. "Thermodynamics" 2nd Ed.
      McGraw-Hill Book Company, 1948

A2   L. C. Denny, L. L. Tuxon and B. E. Hall
      "Handbook Butane-Propane Gases", Chilton Co., 1962

A3   Kohler Electric Plant Catalog, Kohler, Wisc., 1963

A4   Internal-Combustion Engine Institute, "Engine
      Installation Manual", Chicago, First Edition, 1962

A5   Cavileer, A. C., "Investigation of Piston Ring Wear
      Using Radioactive Tracer Techniques", SAE Paper
      S 345, 1962

A6   National Fire Protection Association, "Standard for
      Chimneys, Flues and Vents", Bulletin 211

A7   Kohler Company, "Installation Manual", Kohler, Wisc.

A8   Windcharger Corporation, "Winco Generators",
      Souix City, Iowa

A9   Nat. Elect. Mfgrs. Assoc., "Locked Rotor Current for
      Single Phase, Fractional HP Motors", No. MG1-4.08

Generators

B1   Miscellaneous leading engine-generator manufactorer's
      bulletins such as Kohler, Onan, Kato, Leach, U.S.
      Motors, Wincharger, Homelite, Georator, Pincor, and
      Alliance Products Co.

B2   NEMA, "Motors and Generators", Publication No. MG1-1959

Rankine-Cycle Devices

C1 Lauck, F. W. and Overbye, V. D., "Novel Power Sources
    for Fallout Shelters", Report No. OCD-OS-62-243
    Office of Civil Defense, March, 1963

C2 Kearton, W., "Steam Turbine Theory and Practice",
    Pitman, 1958

C3 Smith, D. J., Personal Communication, W. H. Eagan
    Co., Philadelphia, April 1963

C4 Nicholls, P., Flagg, S. B., and Augustine, C. E.,
    "Five Hundred Tests of Various Coals in House heating
    Boilers", U. S. Bureau of Mines, Bulletin 276, 1928

C5 Doyle, F., Personal Communication, Perfex Corp.,
    Milwaukee, Wisconsin, May 1963

C6 Skrobisch, A., "High Speed Frequency Power", Elec. Mfg.,
    Vol. 39, No. 2, Feb., 1947, pp 120-124

C7 Schwardt, G. O., "A 400-Cycle Aircraft Motor", Elec.
    Eng., Vol. 64, July, 1945, pp 508-512

C8 Keen, C. F., Personal Communication, Keen Mfg. Co.,
    Madison, Wisconsin, May 1963

C9 Lauck, F., Myers, P., Uyehara, O., "An Engineering
    Evaluation of Energy Conversion Devices", SAE Trans-
    actions, 1963, pp. 41-50.

C10 Hazard, H., et al "Multifueled-Thermal-Energy-Conversion
    Systems", Progress Reports 1-6, U.S. Army ERDL,
    Fort Manmouth, N. J., 1963.

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